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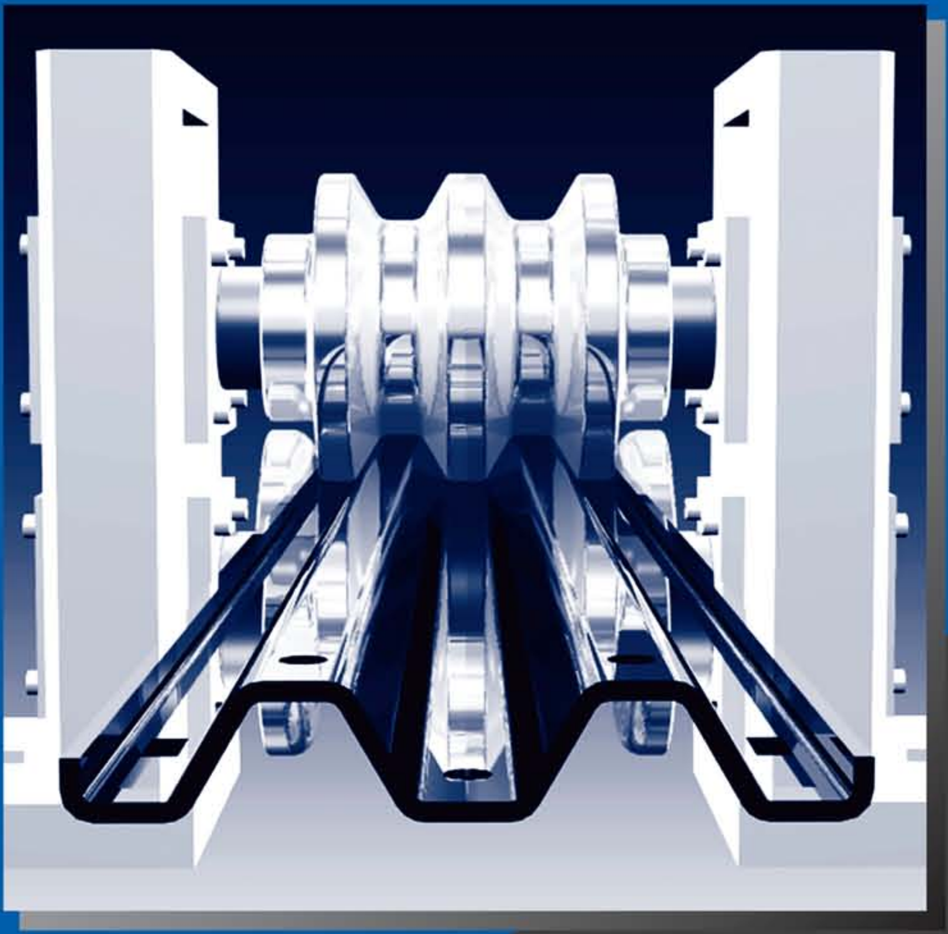

edited by
George T. Halmos

Roll Forming Handbook

MANUFACTURING ENGINEERING AND MATERIALS PROCESSING

A Series of Reference Books and Textbooks

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Roll Forming Handbook

edited by

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Preface

Roll forming has a significant and a puzzling peculiarity. The significant aspect is that during the last half century, roll forming has developed to be the most productive metal forming technology. About 35 to 45% of all the flat steel produced by the North American steel mills is processed through roll forming mills; this is more steel than used by the automotive industry. The puzzling aspect of roll forming is that in spite of seeing and using hundreds of roll formed appliances, automotive, building, agricultural, office furniture, storage, and other products, hardly anybody outside the profession has ever heard of roll forming. Most people have some perception or image about forging, casting, and welding, but not roll forming. No popular books or plays are about roll formers. Most importantly, the available technical literature is limited. Those working in the industry have a difficult time learning the trade and in explaining to others what their profession is, what they are doing, and, indeed, what roll forming is.

During the 100-year history of roll forming, thousands of knowledgeable tool, equipment, and product designers and users have worked and are still working in this industry. Unfortunately, most of the experience gained by those roll former operators, setup personnel, and designers has never been documented in any meaningful way, and it remains the secret of the individuals. Of all the published papers and research reports, only a limited number can be readily interpreted and applied in roll forming plants.

The aim of this handbook is to fill this gap in knowledge and to provide comprehensive information about roll forming equipment to operators, supervisors, engineers, and tool and equipment designers, as well as to students interested in this trade. The text is based on the authors' own experience, enriched with the experience of other individuals willing to share their knowledge with them.

Roll forming is a complex subject. It is possible that readers will search for and cannot find certain missing details. As editor and author, I chose to include those subjects that I thought would be most relevant to both novices and experienced practitioners. Nobody knows everything about roll forming; readers' experiences may differ from those described in this book because of the multitude of factors influencing the quality and quantity of roll formed products. Therefore, readers are encouraged to send their comments, observations, and data to the editor and authors of this book. Certainly, their criticism and the new information will enrich subsequent editions of this handbook.

I was introduced to roll forming by my former boss in the late 1950s. On my first day on the job, he pointed to an uncoiler and explained, "There's where the material comes from, it's formed in the next equipment, which is the mill and then it is cut to length. The rest of it you will learn." And I learned the hard way, by trying to understand the process, reading the few papers on the subject that were available at that time, and taking courses provided by FMA, SME, and a few other organizations. Admittedly, my most valuable experience stems from setting up mills with rolls I designed and operating the roll forming line. I never forgot the mistakes I made. However, a lifetime would not be enough to gain all of the experience that I learned from mill operators, setup personnel, suppliers, colleagues, and friends who were willing to share their "hard learned" knowledge with me.

Special acknowledgment to Andy Baird, Tony Srnec, and to a long list of co-speakers at roll forming conferences: Tim Gutowski, Don Hill, Joe Ivaska, Barlow Brooks, Leo Gale, and many others. I also learned a lot from the comments and questions of the audience at my presentations.

Thanks to those experts who took the time to read and correct parts of my original manuscript: Roll Design — Tony Rhodes, Fred Gradous; Materials — Shrikant Bhat, Jim Cran, Steve Forrest, Gil Kaufman, Alan Pearson, Paul Schurter, and others.

The writing of this book was also made possible by the understanding and support of my family, including the correction of my English grammar by my children, typing of the text by my efficient secretary Fanny Tam, the preparation of drawings by George A. Dobrev and several other engineers, and the kind cooperation of about 30 companies.

George T. Halmos

Editor

George T. Halmos, consulting engineer, has been the president of Delta Engineering Inc. in Toronto, Canada since 1979. He graduated as a mechanical engineer from the Technical University of Budapest in 1950. He worked for 4 years as a research engineer and was head of the largest material testing laboratory in middle Europe. He was also a lecturer at the Technical University of Budapest from 1950 to 1956. In 1957, he joined a subsidiary of Alcan in Toronto as a design engineer. For the next 17 years, he worked for the largest sheet metal manufacturing company in Canada (Westeel-Rosco Ltd.) in the positions of project engineer, then works manager and chief engineer. In 1976, he joined B&K Machinery International Ltd. as general manager of the Roll Forming Division. He has participated in the engineering committees of the Canadian Steel Sheet Building Institute, the Canadian Steel Pipe Institute, and the Canadian Standards Association Metric Committee. He is a member of several professional associations and is a registered consulting engineer. He authored approximately 50 technical papers and has made over 100 presentations on various subjects on roll forming.

Currently, he provides consulting and troubleshooting services, conducts management and operator training courses, and carries out research and development in all aspects of sheet metal manufacturing technologies, with special emphasis on roll forming; customers range from the smallest shops to the word's largest manufacturing companies.

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1

Introduction to Roll Forming

George T. Halmos
Delta Engineering Inc.

1.1 Introduction to Roll Forming 1-1
A Short History of Using Metals • Forming of Sheet Metals • What is Roll Forming? • Basic Requirements

1.1 Introduction to Roll Forming

1.1.1 A Short History of Using Metals

Our ancestors used wood and stone tools for over 1.7 million years, give or take a few hundred thousand years, before making use of metals. It was only around 6000 B.C. when naturally available gold (and later copper), meteorite iron, and a few other metals were shaped by hammering to make ornaments, tools, and weapons. Afterwards, our forefathers discovered how to reduce ores, melt and alloy metals, and utilize them for more elaborate products.

Gold was mainly used for jewelry because it is too soft for implements. Copper was only slightly harder, but by adding arsenic and tin to copper, the early Bronze Age smiths could produce good-quality axes and other articles. Gradually, more and more bronze articles were used and the Bronze Age superseded the Stone Age.

Gold, copper, tin, lead, silver, iron, and mercury were the only seven known and used metals until the thirteenth century and only five more metals were discovered up until the seventeenth century. Today, we know that about two thirds of all known elements are metals.

The first iron products dated back to 3000 to 4000 B.C., but they were scarce and expensive. The edges of iron implements were too soft; therefore, iron articles were suitable for ornaments but not for tool and weapons. The discovery of carbonizing around 1200 to 1300 B.C. brought major change and heralded the beginning of the Iron Age. Steel products became better for tools and weapons. Transition was slow, but eventually cast and forged iron products replaced bronze in most areas. Furnaces became larger and steel became better. The early smiths produced excellent quality axes, chisels, hoes, swords, and other implements. In 1350, the ironmakers of central Europe succeeded in melting and casting iron trough the use of primitive blast furnaces [438].

Making complex items, such as body armor assembled from hundreds of matching pieces of hammered plates and wires, required considerable skill and experience. The process was extremely labor-intensive because of the long hours of hammering required. Actually, up to the seventeenth century, to the dawn of the Industrial Revolution, every noncast item, from ornamental to utility was made by hand, through labor-intensive forging. Not many people could afford to own metal products.

During the Industrial Revolution of the eighteenth and nineteenth centuries, many of the handtools used in metal manufacturing were gradually replaced by power-driven machinery. Water wheels, steam engines, and, later on, electrical motors provided an abundant quantity of power. In 1855, Bessemer patented the first modern steel-making method in England, a process that provided large quantities of better quality steel. Originally, steel was intended for castings (canons), but eventually most of it was processed by forging, using big, powered presses.

One of the most significant and least-heralded achievements of the Industrial Revolution was the replacement of the ancient art of hammering (forging) with pairs of rotating rolls to change the shape or the thickness of the metals. Based on the forging experience, and knowing that steel is more pliable when it is hot, the rolling process was completed at high temperatures. Rolling reduced the thickness and increased the surface area in contact with air. The rapid cooling of the large surfaces limits the minimum thickness achievable by hot rolling. The introduction of flywheels, clutches, reversible steam engines, and electrical motors contributed to faster steel forming processes, permitting further reduction of the minimum thickness of the rolled products. However, the thinner the metal gets, the larger its surface and the faster the rate of cooling. Therefore, even with the most modern equipment, the minimum thickness of commercially available hot rolled steel is still about 0.060 to 0.070 in. (1.5 to 1.8 mm).

Rolling at room temperature is not a new technology. Primitive cold rolling was used in the fourteenth century for gold and silver. The first true rolling mills of which any record exists were designed by Leonardo da Vinci in 1480 [437]. In the late sixteenth and early seventeenth centuries, pairs of rolls were used to roll flats from soft materials such as gold, lead, and tin, probably at room temperature. Cold rolling was also used to planish tin plates. Room temperature (cold) rolling of steel commenced in the late eighteenth century and became more widely used in the nineteenth century. By the late nineteenth and in the twentieth centuries, an immense variety of hot and cold rolled aluminum, copper, brass, lead, tin, titanium, zirconium, and specialty alloys sheet became commercially available. Without these rolled flat products, our current life and our living standard would be unimaginable.

1.1.2 Forming of Sheet Metals

The name "manufacturing" originates from the Latin *manu* (hand) and *factura* (making). When flat-rolled sheets became commercially available, for a long time, the final products were manufactured, formed, and shaped by hand. Gradually, machines, particularly presses, substituted for most of the hand forming.

A variety of mechanical presses (single-action screw, friction, link-and-crank, and different double-action draw presses) and hydraulic presses were used almost exclusively to blank, form, or draw all sheet metal products until the early twentieth century. Other processes, such as curving, profile drawing, stretch bending, spinning, winding, beading, explosive forming, electromagnetic forming, and hydro forming are also used for forming sheets and plates. However, the combined output of these processes is considerably less than that produced by the presses and later on by roll formers.

Although roll forming was already used in the early 1900s, it was only after the Second Word War when it took over a significant percentage of the fabrication of sheet metal products from press brakes and other types of forming. Owing to the high efficiency of roll forming, the labor content of many products was drastically reduced.

Roofing, siding, farm buildings, grain storage bins (silos), shelving, storage racks, fluorescent light fixtures, electrical products, refrigeration, heating, ventilation, railway cars, power plants, doors, windows, toilet partitions, bicycle wheels, fire places, furniture, appliances, airplanes, spacecraft, swimming pools, and countless other products have all been efficiently roll formed.

In the 1950s and 1960s, rotary encoders were introduced and the applications of pneumatic presses, in-line welding, prepunching, and roll forming prepainted metals spread widely. Eventually, more and more other operations were incorporated into the roll forming lines.

In the 1970s and 1980s, prepunching became more sophisticated through the use of different controls and gagged punches. Innovations were introduced to reduce tool changeover time using rafted construction,[1] side-by-side rolls and other devices. Die accelerating systems became more sophisticated and lengths more accurate. Steels with up to 200,000 psi (1960 MPa) yield strength and many exotic metals were successfully roll formed. In the late 1970s and early 1980s, computer-aided roll design systems were introduced.

In the 1990s, an increased number of programmable controllers and computers have been added to control the lines. The product, as well as the material tolerances, has become tighter and the demand for manufacturing flexibility has increased. Customers pressed equipment suppliers for better quality and more efficient lines, including automated finished-product handling. Competitiveness has necessitated the reduction of the number of operators and in some cases one operator to run two or more lines, at an increased speed, and at a higher utilization rate.

By the 1970s, about 35 to 40% of all sheet products produced by the North American steel mills were processed through roll formers. In the last decades of the twentieth century, roll forming of automotive products became the fastest growing segment of the industry.

The roll forming industry is still growing strongly in the twenty-first century.

1.1.3 What is Roll Forming?

It is not a simple task to describe or explain the concept of roll forming. A frequently used definition demonstrates the complexity:

> To form sheet metal strip along straight, longitudinal, parallel bend lines with multiple pairs of contoured rolls without changing the thickness of the material at room temperature.

Similar to many other definitions, the above one also has exceptions.
To form sheet metal strip along straight, longitudinal, parallel bend lines, but

- The products often exit the roll former curved or in a spiral form
- The products can have bend lines 90° to the longitudinal bend line
- The bend lines are not always parallel (intentionally)
- The bend lines are not always straight (occasionally unintentionally)

with multiple pairs of contoured rolls, but

- To achieve the desired shape, the roll formers may apply bronze shoes, plastic guides and, especially during setup, 2×4s. If the wood pieces are effective during the setup, then they are clamped to the machine. Once the clamps are taken away, the 2×4s are strapped to the equipment. If they are still functioning well after a month or so, then they are painted in green and became part of the line [431]

without changing the thickness of the material, but

- The thickness is almost always reduced at the bend lines
- In thin curved products, the outside fibers are thinner than the inside ones
- Mills are built with special passes to reduce the strip thickness at specified locations
- Contrary to good practice, the thickness of the material is occasionally reduced by bent shafts, and far too frequently by the operators

---

[1] Rafted® Rollformer is a registered trade name of The Bradbury Group.

at room temperature, but

- To eliminate the cracking of paint at the bend lines, the material can be preheated just before forming
- Plastic can be roll formed at elevated temperature
- In-line soldering, brazing, or annealing requires elevating the temperature of metal while processing through the equipment
- Titanium was hot roll formed in the late 1960s
- Hot roll forming is a potential new technology.

Roll forming is a flexible process, where both the fundamental rules and the exceptions can be utilized. It has been proven several times that even seemingly impossible roll forming tasks can be accomplished, although it may take a longer time and much more money. On the other hand, it has also been shown that plans to roll form simple shapes can create disastrous results if the basic rules of roll forming are not followed.

1.1.4 Basic Requirements

1.1.4.1 Satisfying Customers

Roll formed products are sold to customers in an extremely competitive market. Customers are always looking for manufacturers who can repeatedly meet with their basic requirements. They are expecting to receive:

- The right *quality*
- The right *quantity* of products
- At the right *time*
- For the right *price*

Companies not able to supply the right quality or the right quantity, at the right time for the right price will lose their customers. However, not consistently meeting customers' expectations or having manufacturing problems is not always the plant's fault. The plant cannot manufacture good-quality products at the right time for the right price if they are not provided with the basic mechanisms to fulfill their obligations.

1.1.4.2 Basic Requirements of the Manufacturing Plant

To successfully meet the demands and outperform the competitors, manufacturing plants must have:

- Good *design* (product drawings) to be manufactured
- Sufficient *run quantities*
- The right *material* to be formed
- Proper *equipment*
- Good *tooling* and
- Knowledgeable, motivated *workforce*

Good design (products that can be manufactured without extreme hardship). Most plants have experience with products that cannot be efficiently roll formed, or sometimes not roll formed at all. The product can be too complicated for the available equipment, or the dimensions or tolerances are beyond the capabilities of the equipment or tooling.

Sufficient run quantities. If the run quantities are below an economical minimum level, then high setup cost can reduce efficiency unless the plant has a special-purpose line set up for that specific product. Very high run quantities may reduce product costs but can increase inventory, product-handling cost, and storage space requirement.

Acceptable quality material. Running across "bad material" is not a rare occurrence. Perhaps the supplied material was either unsuitable for the product, or it could have been incorrectly specified.

However, when troubleshooting of the equipment and tooling does not yield quick results, the material is far too frequently, and often incorrectly, blamed for the bad products.

Proper equipment suitable for forming the product. There is no plant without complaints about the roll forming lines. Frequently, the complaints are justified; sometimes, it is the results of procuring a line of insufficient capacity or bad quality, or of neglected maintenance or abusive usage by the operator. The life of a good-quality, reasonably well-maintained roll former can be over 50 years. Most malfunctioning equipment problems are corrected in the first year, and the mill will operate with reasonable reliability. However, incorrectly specified, slow, weak, or low-quality lines cannot be made competitive against faster and better lines.

Good tooling. Roll forming lines are equipped with several sets of tooling during their lifetime. Good-quality, operator-friendly, properly set up tooling is essential to produce good-quality products at reasonable price.

Knowledgeable, motivated work force. It has been stated repeatedly that the greatest asset of a company is its people. A company can have an excellent product, good material, the best equipment and tooling, but is still unable to produce competitively without knowledgeable people. Continuous education of the operators and other employees, combined with motivation, is crucial to good productivity and profit.

2

Roll Forming Mill

2.1 General 2-1
2.2 Mill Types 2-1
Cantilevered Mills • Duplex Mills • Through-Shaft Duplex Mills • Standard (Conventional) Mills • Double-High Mills • Rafted (Plated, Cassetted) Mills • Side-by-Side Mills • Pull-Through Mills • Spiral-Tube Mills • Truck-Mounted Mills • Special Mills
2.3 Mill Components 2-18
Mill Bed • Stands • Shafts • Power Train • Side-Roll and Cluster-Roll Stands • Guides Between Passes • Straightener • Lubrication System • Shaft Shoulder Alignment • Installation of Other Units in the Mill
References 2-32

George T. Halmos
Delta Engineering Inc.

2.1 General

The heart of the roll forming line is the mill. The mill provides the power and support to the tooling that forms the metal. The complete roll forming line is aligned with the shaft shoulders of the roll forming mill.

The variations in mill design are unlimited, but mills can be classified as cantilevered, duplex, through-shaft duplex, standard (conventional), or rafted (plated). Those not fitting into any of these categories may be considered as "special mills."

2.2 Mill Types

2.2.1 Cantilevered Mills

The shafts of the cantilevered mills are supported at one end only; hence, they are sometimes called "overhanging" or stub-type mills (Figure 2.1).

Cantilevered mills, producing lock-forms at the edge of sheets, have been popular with sheet metal workers for a long time. They are low-cost, nonsophisticated machines, and require little adjustment. The cantilevered mills become more popular and have been used to form many simple, narrow sections (Figure 2.2).

To utilize the mill for two sections, the opposite side of the "cantilevered" shaft ends can be tooled to form another section (Figure 2.3).

The advantages of the cantilevered mills are:

- Relatively low cost
- Capability to form the edge of sheets of any width

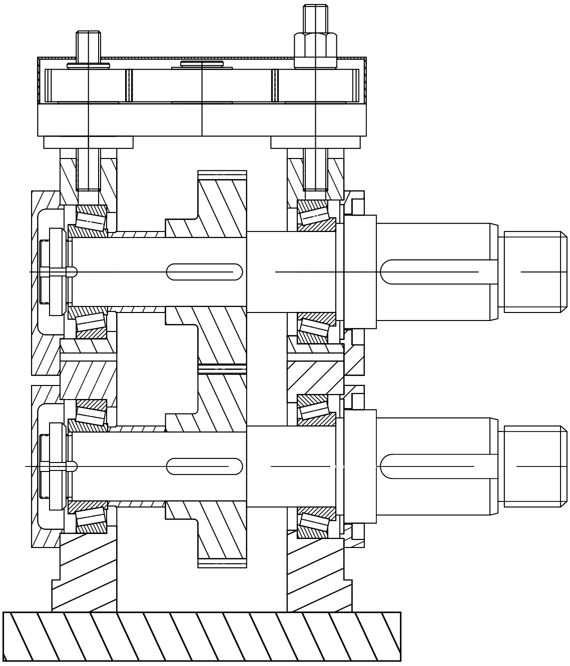


FIGURE 2.1 Cross-section of cantilever mill.

TABLE 2.1 Shaft Diameter Selection Examples

Roll Space (in.)	Yield (ksi)	Thickness (in.)	Factors	Revised Thickness	Shaft Diameter (in.)
12	50	0.036	1	N/A	1.5
36	50	0.036	1	N/A	2.75
36	50	0.020	1	N/A	2.5
48	50	0.020	1	N/A	3.0
48	100	0.020	$\times \sqrt[6]{\frac{100}{50}}$ (100 ksi yield)	= 0.022 in.	3.0
48	50	0.020	× 2 (stretched groove)	= 0.040 in.	3.5
12	50	0.375	1 (check bearing)	N/A	4.25
48	50	0.020	× 0.6 (edge forming)	= 0.012 in.	2.75

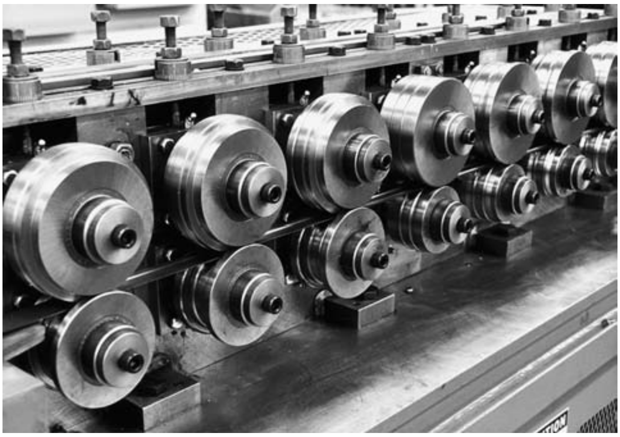


FIGURE 2.2 Cantilever mill. (Courtesy of Metform International Ltd.)

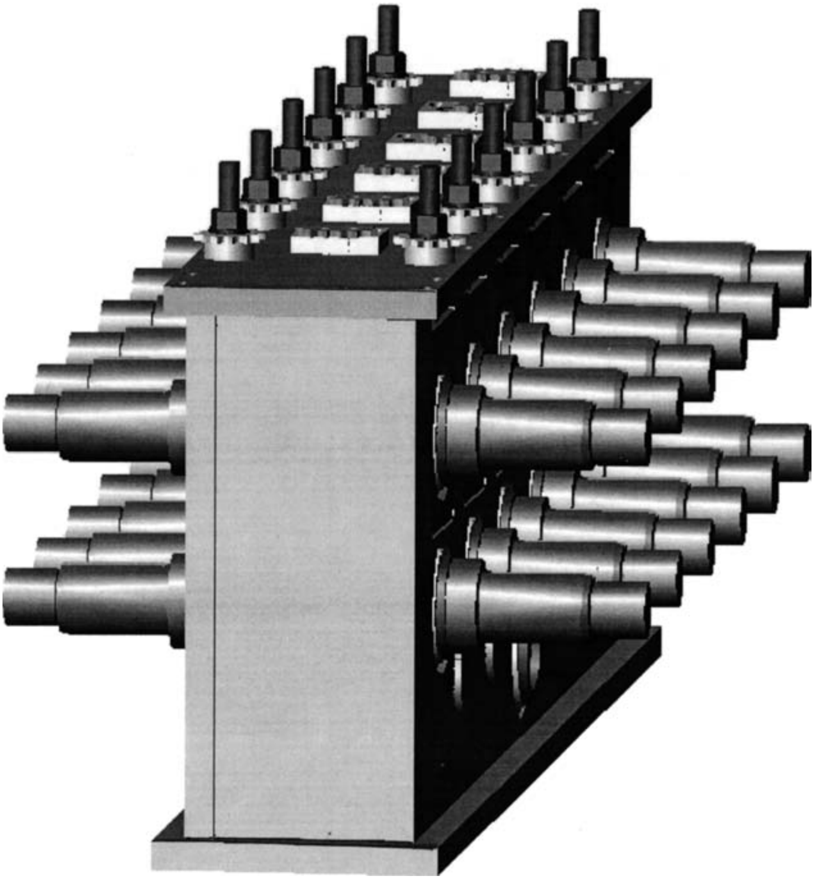
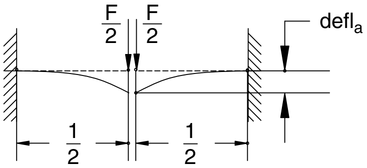


FIGURE 2.3 Cantilever mill with rolls at both ends of the shafts.

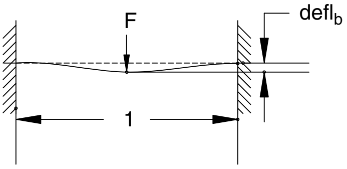
The disadvantages of the cantilevered mills are:

- Singular adjusting screw makes it difficult to set the required roll gap.
- Double-adjusting screws makes it very difficult to adjust the shafts up or down, while keeping the top shaft parallel to the bottom shaft.
- The deflection of the two opposing shafts under the same load is approximately four times the deflection of the same shaft supported at both ends (Figure 2.4). Owing to the larger deflection of the cantilevered shaft, the shaft length (and the maximum formed width) is limited.

The first two shortcomings can be eliminated by using double-adjusting screws connected with gears (one shaft-height adjusting screw rotates the other one). The deflection can be reduced by



(a) supported at one ends



(b) supported at both ends

$\text{defl}_a = 4\ \text{defl}_b$

FIGURE 2.4 Cantilevered shaft deflects four times more than a shaft supported at both ends.

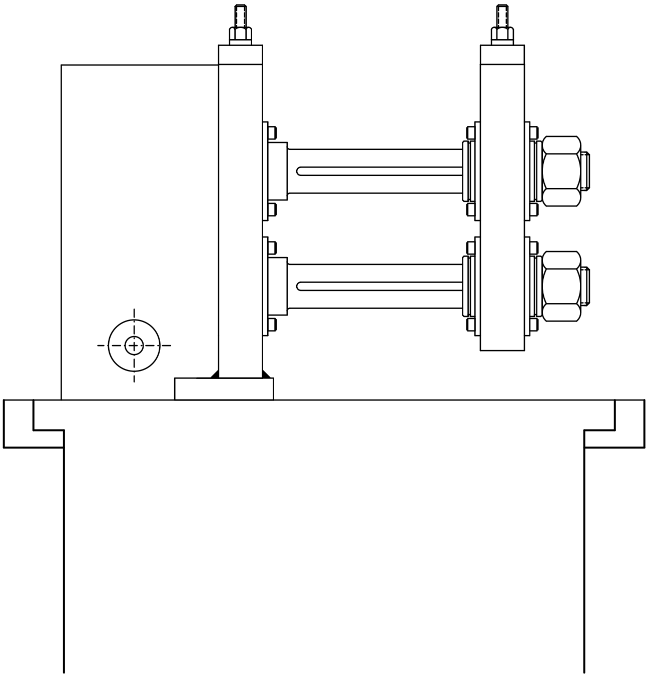


FIGURE 2.5 Connecting the operator side of the cantilevered shafts reduces deflection.

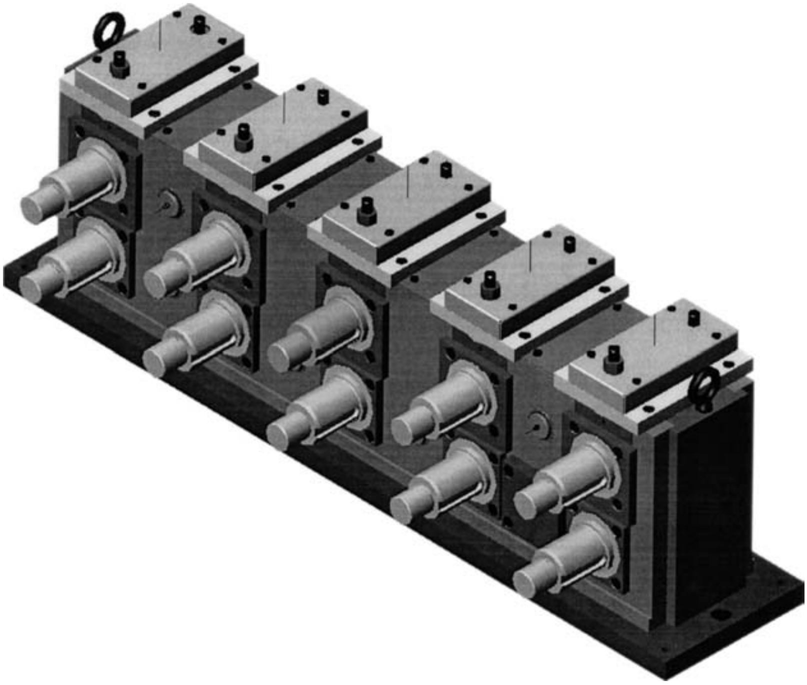


FIGURE 2.6 Rafted cantilever mill stand. (Courtesy of CompuRoll Inc.)

using larger shaft diameter shafts or by applying a connector (yoke) between the top and bottom shafts at the operator side (Figure 2.5). This connecting unit can be applied to form narrow sections only. Using cantilevered mills, the maximum width of the formed part of the product seldom exceeds 4 in. (100 mm).

To facilitate fast profile changes, rafted (plated) cantilevered mills have been developed (Figure 2.6). The plate, supporting the stands, shafts, and tools, can be lifted off and exchanged with another one within a few minutes.

2.2.2 Duplex Mills

Two cantilevered mills facing each other are called a duplex mill. Duplex mills have one common base and drive (Figure 5.47). They can form both edges of narrow or wide products leaving the center flat. The minimum strip widths depend on how close the opposing rolls can be pushed together, and the maximum widths usually depend on how far the two mills can be moved from each other. The width of the formed products can be changed quickly by adjusting one or both sides of the duplex mill in or out (Figure 2.7).

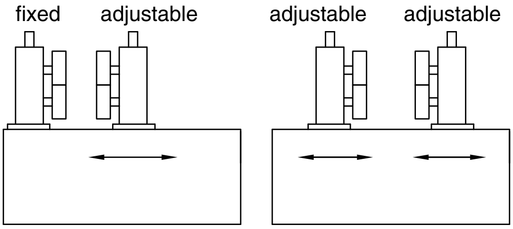


FIGURE 2.7 Duplex mill with one or two adjustable row of stands.

Duplex mills have the same advantages and disadvantages as the cantilevered mills, except that the shaft end connecting pieces cannot be used. Some duplex mills have shafts extended at the other side of the mill, which can be used to form narrow sections.

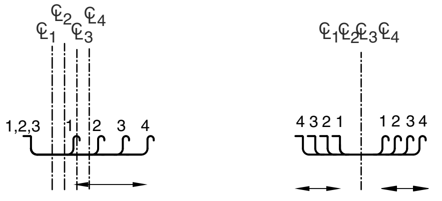
Duplex mills either have one side fixed and the other one adjustable, or both sides adjustable. Adjustment of a side is usually accomplished by placing all stands on one plate, which, with proper guides, can be moved in and out, thus changing the gap between the two cantilevered mills.

For duplex mills with one adjustable row of stands, the centerline of the product changes with width change.

In the case of duplex mills with two adjustable rows of stands, the centerline of the products remains in the same position. This arrangement is used when holes are prepunched at or around the centerline, either when the cutoff die has to be kept symmetrical or for other reasons when it is advantageous to keep the centerline in the same position (Figure 2.8).

The width adjustment can be manual or motorized. The most sophisticated lines have programmable controller or computer-controlled width adjustment. Forming rolls installed in a cantilevered or duplex mill are seldom exchanged to produce different profiles.

It is highly recommended that rolls are installed with the same length through the mill. This makes it very easy to check shoulder alignment (by placing a "straight edge" to the end of the rolls) and to check whether the two rows of stands are parallel (by checking the gap between the tooling).



(a) one side adjusted (b) both sides adjusted

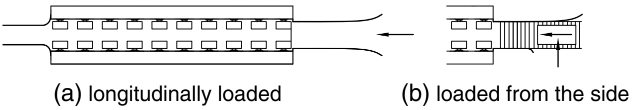
FIGURE 2.8 Channels with variable widths produced in duplex mill with one or two adjustable row of stands.

Both the single cantilevered and duplex mills must have long entry and reasonably long exit guides (Figure 2.9). The uneven roll pressure, uneven or asymmetric forming, and bent shafts can generate uneven driving forces, resulting in a skewed entry or exit of the product (Figure 2.10).

Firmly attaching the entry and exit guides to the entry and exit stands eliminate the individual adjustment of the guides when the width is changed. Both the entry and exit guides should have curved (“fish-mouth”) entry sides. For manual loading from the side, it is recommended that the entry guide opposite to the loading side is longer than that at the loading side. The operator can load and push the precut blank against the longer side and then push it into the mill. The length of the guides is not as critical if the mills are fed with coils and the parts are postcut.

Bending short legs at the edges can create other problems. The horizontal vector of the bending forces pushes the strip inward towards the center. The shorter the bent leg, and the larger the width and thickness ratio of the flat, unsupported center part, the greater the buckling tendency will be (Figure 2.11).

Center support is used to avoid buckling of the wide flat center part. Because of the self-weight of the material, the support is usually placed underneath the center part. However, if the horizontal vector of the forces is large and the support prevents the sheet to buckle downwards, then it can buckle upwards. To avoid upward buckling, additional support is placed on the top of the center part. When the width is changed, the location (and possibly the number of the center supports) has to be changed too. These adjustments have to be taken into consideration at the design stage. It is also important that the support should not scratch or mark the product. Embossing, lancing, louvering, or other similar operations


(a) longitudinally loaded

(b) loaded from the side

FIGURE 2.9 Precut sheets fed into roll forming mill requires long entry and exit guides.

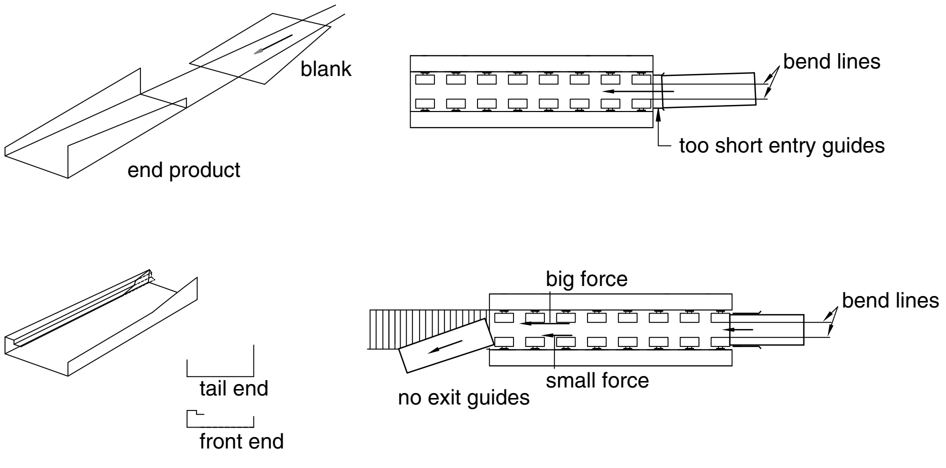


FIGURE 2.10 Misaligned entry or uneven forces at the two edges can create products with unacceptable qualities.

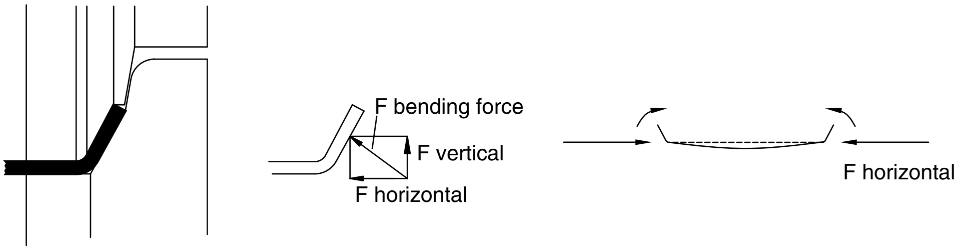


FIGURE 2.11 The horizontal vector of the bending forces can buckle the center of unsupported products.

ahead of the mill can make proper support against buckling more complicated.

In spite of these drawbacks, the duplex mills are frequently used to form shelving, doors, edge-formed sidings, and many other products where unlimited adjustability between the minimum and maximum widths is required.

In some cases where forming of the wide, flat center section is required (such as mobile home sidings), one (or more) pairs of grooving rolls are placed ahead of the first pass. The shallow flutes are stretched in the material before the edges are formed in the mill (Figure 2.12).

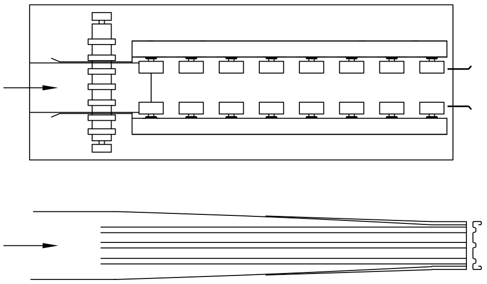


FIGURE 2.12 Forming the center of a panel with "grooving rolls" in a duplex mill.

Because roll change is relatively complicated, it is seldom made in the cantilevered and duplex mills. To provide more versatility, special duplex mills have been developed with quick exchange of the inside and outside rolls (Figure 2.13).

With duplex roll forming mills, it is very easy to change one dimension of a product; for example, the web height ("*h*") or the leg length ("*l*") of "C" channels. If both dimensions have to be changed (web height and leg length, marked *h* and *l*, respectively (Figure 2.14), then two independently adjustable duplex mills can be combined, using a common drive. Changing the width in the first mill will change the leg length (*l*), and changing the second mill will change the web height (*h*). The two mills have one common centerline. This method is used to form drawers for metal filing cabinets, "C" sections, and other products. A third dimension, the lip width (marked "c" in Figure 2.14), can also be changed by adjusting the strip width that enters into the first mill, or by having a third duplex mill incorporated into the unit (Figure 2.15). A mill tooled for "C" channels can also produce "U" channels without tool change.

Because the entry guides and the straighteners are attached to the mill stands, changing the product dimensions is very simple and quick. Some of these mills are equipped with servo motors and programmable controllers or computers. A line containing prepunching and cutting presses can produce

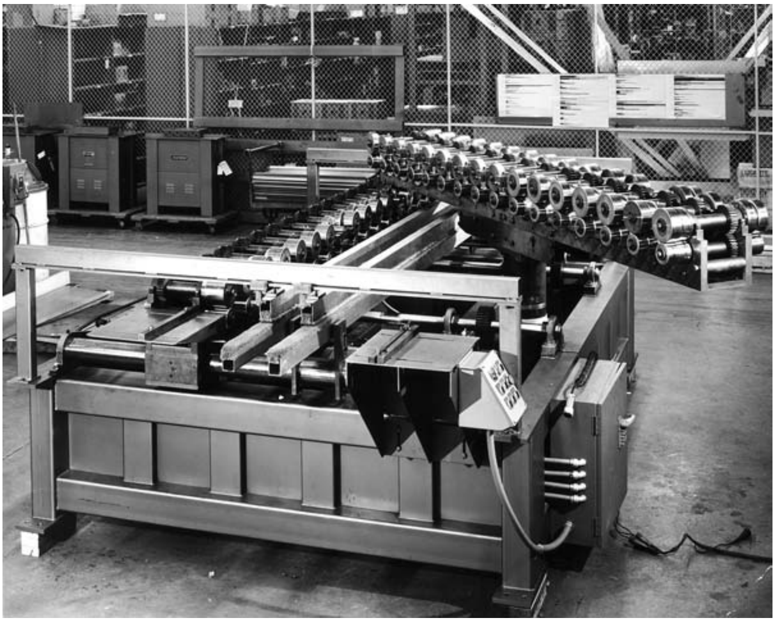
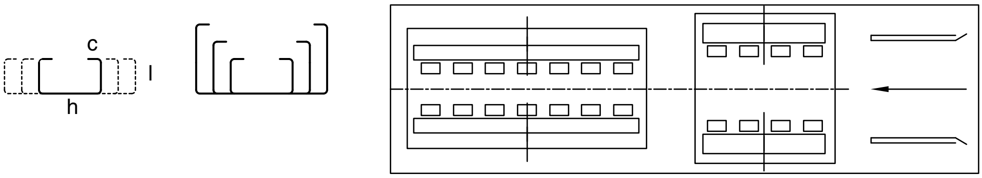


FIGURE 2.13 Quick exchange of roll sets in a duplex mill. (Courtesy of The Lockformer Co.)



(a) second duplex mill (b) first duplex mill (c) entry guide

FIGURE 2.14 Adjusting web width and leg length by using a “double” duplex mill.

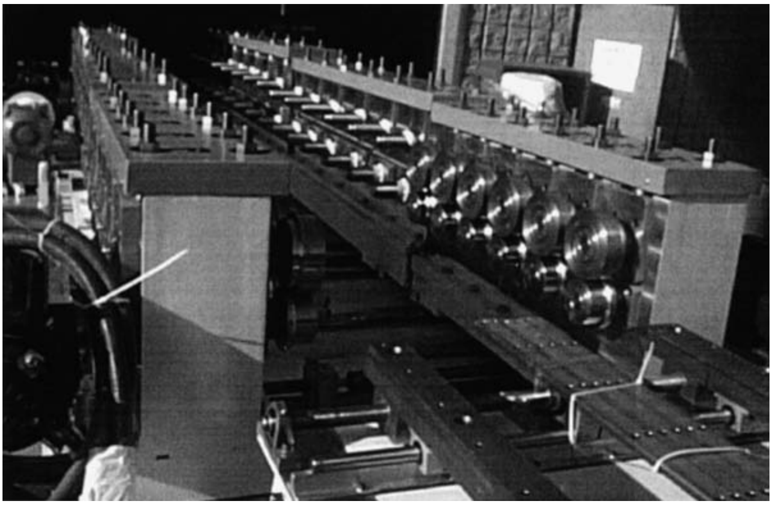


FIGURE 2.15 Triple duplex mill for U and C channels or other product. (Courtesy of CompuRoll Inc.)

infinite varieties of “C” channels (studs) and “U” channels (tracks) within the parameter of the machine, without tool change. Frequently, the only requirement is to enter the part number (or dimensions) and the required quantities into the control unit. The product dimension changeover time can be as low as 1 to 2 min.

Another quick-change “C” and “Z” purlin mill is forming one edge of the product up. At the other edge, the top and bottom rolls can be easily exchanged by either rotating each stand 180° around a shaft or deflecting one leg up for the “C” channel or down for the “Z” section (Figure 2.16). These arrangements enable the production of “C” and “Z” sections on the same machine without tool change.

2.2.3 Through-Shaft Duplex Mills

The through-shaft duplex mill (Figure 5.51) is a combination of the duplex and conventional (standard) mills. The main characteristics of the through-shaft duplex mills are:

- The through-shafts deflect less than the cantilevered shafts.
- Rolls are mounted on sleeves.
- Sleeves are attached to the stand at each side.
- All the operator-side stands are mounted on a common plate, which can slide in or out, thus changing the distance (roll lengths) between stands. Other types of mills allow both sides to move more in and out.
- Sleeves with the mounted rolls are keyed to and sliding in and out on the shafts.

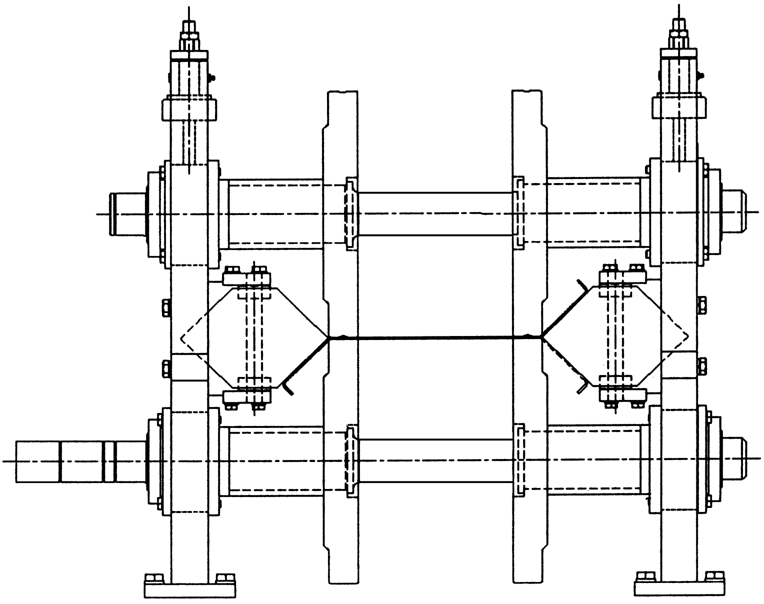


FIGURE 2.16 Producing "C" and "Z" sections in a quick-changeover special duplex mill. (Courtesy of The Bradbury Company, Inc.)

- Through-shaft can carry center rolls between the two edge-forming rolls. These center rolls can support or form beads into the products.

The advantages of the through-shaft duplex mill are:

- The reduced shaft deflection permits the forming of thicker/higher strength material than that of the duplex mills with the same shaft diameters.
- The carrying rolls can support both the top and bottom of the center part of the product.
- It is relatively simple to incorporate forming at the center part of the product.
- Through-shaft duplex mills do not have restriction on the formed width at the strip edges while duplex mills are restricted to form the relatively narrow edges (4 in. or 100 mm) of the strip.

The disadvantages of the through-shaft duplex mill are:

- More expensive than the duplex mill.
- Slightly larger diameter rolls are required because they are mounted on sleeves.
- Relocating the center rolls can be cumbersome.

Many of the variations described in the duplex mills, such as installing two mills in one line, can also be applied to through-shaft duplex mill.

2.2.4 Standard (Conventional) Mills

The shafts of the standard (conventional) mills are supported at both ends (Figure 2.17, Figure 5.54, and Figure 5.77). This design enables building and use of the mills for materials with any width and thickness. Therefore, standard mills are the most popular machines used to roll form metals.

In most cases, the drive-side (inboard) stand holds the shafts in position and accommodates the drive. The operator-side (outboard) stand supports the other end of the shafts. This stand is removable to facilitate roll changes. Both the operator- and drive-side stands are fastened to a common base.

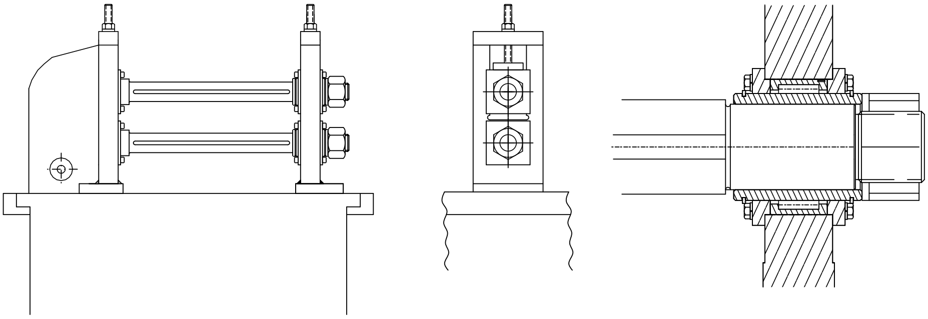


FIGURE 2.17 In the conventional (standard) mill, both ends of the shafts are supported.

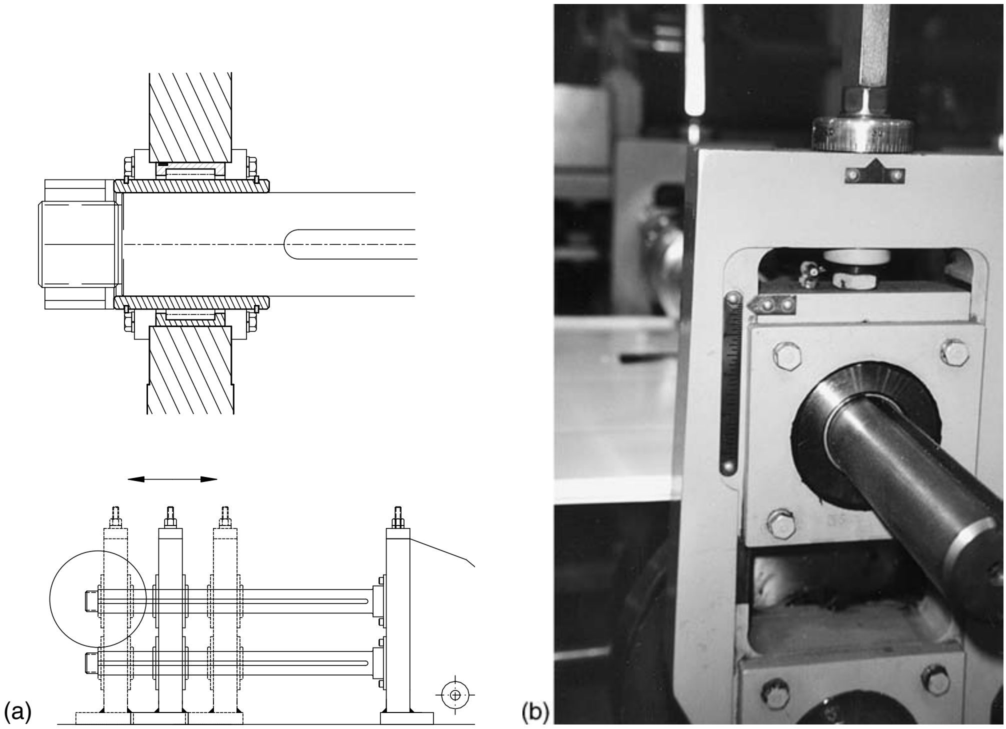


FIGURE 2.18 Conventional mill with adjustable roll space.

The drive-side stands are fixed at one location. The operator-side stands are in most mills also fixed at one position (Figure 2.17). In other types of mills, the operator-side stands can be placed into different locations along the shafts to accommodate wider and thinner material, or narrower but thicker material (Figure 2.18a,b).

The construction of the mill stands and other components is described in more detail in Section 2.3.

2.2.5 Double-High Mills

To satisfy the demand for roll forming two profiles in a limited plant area with quick profile changeover, the "double-high" mills have been developed (Figure 2.19). The double-high mills have alternating short and tall stands. Rolls for one profile are installed in the short stands, and rolls for another profile are mounted on the tall stands. The lines have one uncoiler and one cutoff press. If the material is fed into the

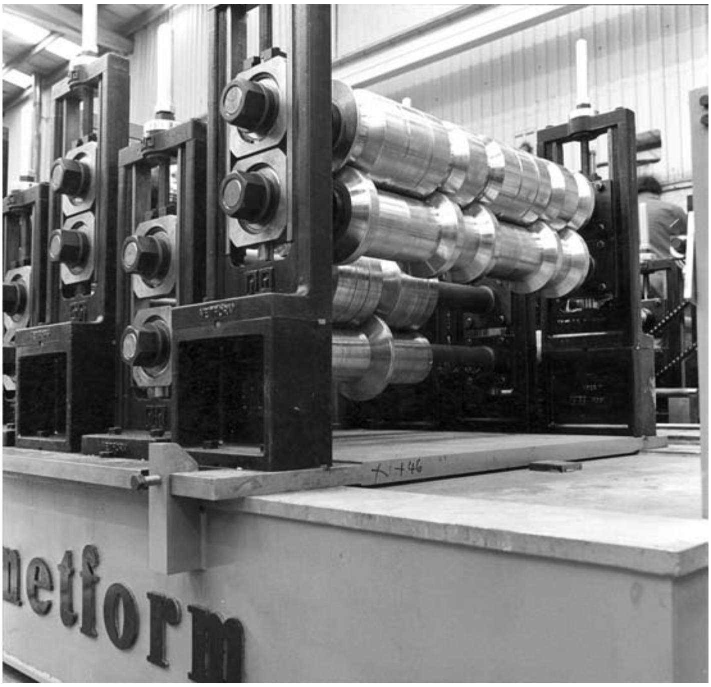


FIGURE 2.19. Double-high mill. (Courtesy of Metform International Ltd.)

lower-level rolls, then one profile (e.g., farm sidings) is formed. If the coil is fed into the upper level rolls, then another profile (e.g., farm roofing) is formed.

To accommodate the profiles exiting at two different levels, the cutoff die also has two levels. The handling equipment for finished products beyond the cutoff die must be adjustable up and down to suit the two product exit heights.

Double-high mills save space, and the changeover time between two products is relatively short. However, because of the crowded condition, it is difficult to install side-roll stands, to make adjustment, or to check the forming conditions.

2.2.6 Rafted (Plated, Cassetted) Mills

The development of rafted mills was a major breakthrough in reducing roll change time from 8 hr or more on a large panel mill (or 4 hr on a smaller mill) to between 30 and 45 min and as low as 5 min. The mill has a bed on which the drive is located and the interchangeable plates are placed. The plates are holding four to eight or more stands (Figure 2.20). The number of stands on a plate is usually restricted by the lifting capacity (crane) at the user's plant.

Both the operator-side and the drive-side stands are typical operator-side-type stands, complete with shafts and tooling. The drive-side stands usually have larger bearing blocks to accommodate pairs of cone bearings which rigidly hold the shafts in position during the operation and when the operator-side stand is removed for occasional roll change.

To allow quick plate (profile) change, the drive must have quick disconnect/connect feature. To further reduce the changeover time, only the bottom shafts are usually driven by the drive train firmly attached to the bed. All or some of the upper shafts can be driven by gears located at the drive-side end of the mill shafts.

The plates (rafts) must be accurately located on the mill bed. The early "pin-type" locators are not considered a good solution because it is difficult to repair the wear and tear on the pin and the hole

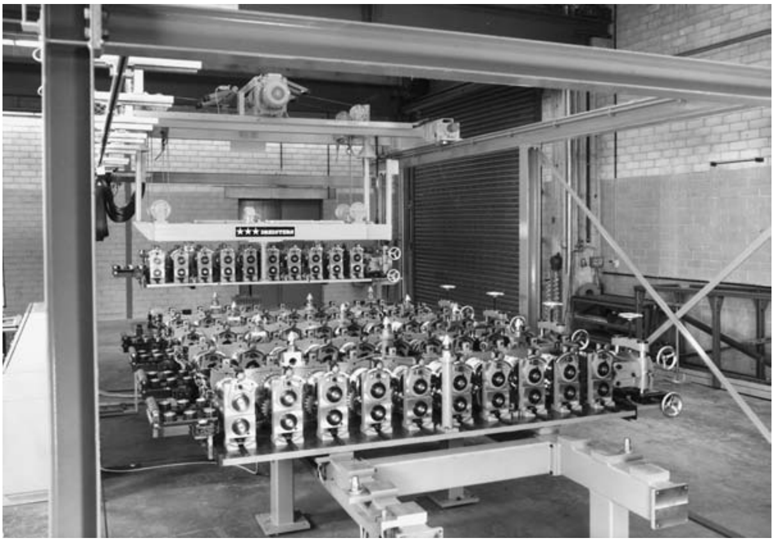


FIGURE 2.20 Rafted mill (Courtesy of Dreistern, Inc.).

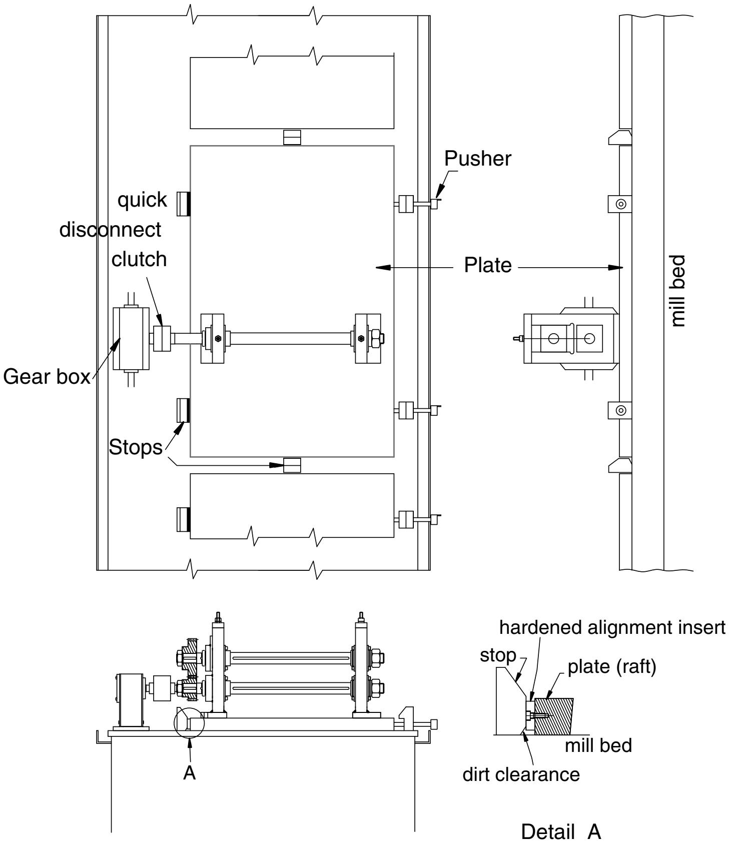


FIGURE 2.21 Construction of locating locks and mechanism for rafts.

(or sleeve). It is also troublesome to make additional sets of rafts that fit exactly onto the pins and, at the same time, provide accurate shoulder alignment. Two stops at the drive side of the bed for the longer side of the plate and one stop at each short side are sufficient for accurate location (Figure 2.21).

To provide the shortest possible tool change time, hydraulic pushers and clamps can be used. The upper surface of the mill bed does not have to be fully machined. It is sufficient to machine only the protruding surfaces where the plates (rafts) rest.

The four lifting lugs attached to the plates should provide a reasonable good balance, and the lifting attachments (bars or chains) should not rub against the tooling, shafts, or stands.

To reduce changeover time, all the additional components such as the entry guides, side-roll stands, and straighteners should be permanently attached to each set of plates.

Saving of floor space can be achieved by storing the plates of a profile on top of each other (Figure 2.22). Tubes or other components (Figure 5.158) supporting the upper plate(s) should be incorporated in the plate design.

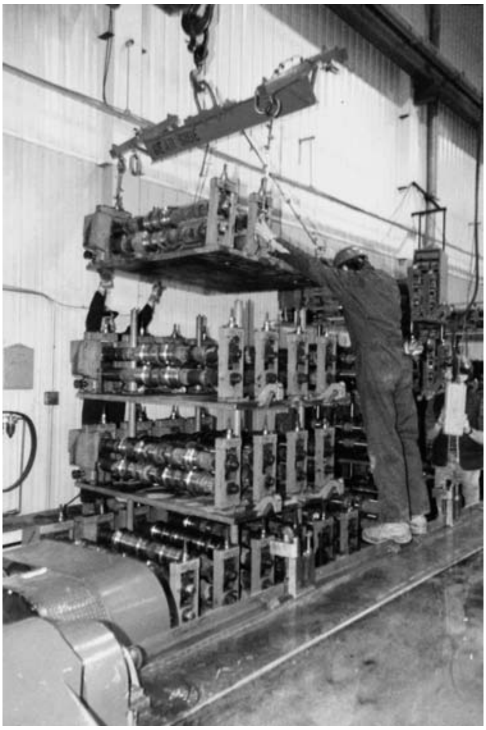


FIGURE 2.22 Storing plates on top of each other reduces floor space requirement (Courtesy of Ideal Roofing Co. Ltd.).

2.2.7 Side-by-Side Mills

Tool changeover time can further be reduced by mounting more than one set of tooling on the mill shafts. The simplest arrangement for the narrow sections is to install two sets of rolls on common shafts (Figure 2.23). The uncoiler, the prepunched press (if required), and the cutoff press are in line with one set of rolls. When profile change is required, the mill bed is moved sideways to align the second set of rolls with the other equipment. The complete changeover takes less than 2 min. Depending on the length of the mill bed, two, three, or more pairs of supporting rolls (casters) are attached to the bottom of the mill bed. The rolls are moving on rails embedded into the floor. Brass slides or linear bearings are also used to move the mill sideways. The movement is accomplished by electrical motor driven screws or by other means (e.g., hydraulic cylinders). Moving the mill bed against positive stops assures proper alignment. Occasionally, the mill remains in position while the uncoiler and the press (hydraulic) are moved sideways.

The advantage of this "side-by-side" arrangement is the high up-time. The disadvantage is that setting and adjusting one section will at the same time change the setting of the other section. However, this shortcoming can be easily overcome by using one or two more extra stands. At the more frequently adjusted, critical passes, only rolls of one set are installed. At the critical passes of the other section, only rolls for the other section are installed. This arrangement ensures that adjusting one section will not influence the other section.

It should also be noted that both sets of rolls must have the same pitch diameter and that recutting one set of rolls will necessitate the recutting of the other. During setup, the rolls closer to the shaft shoulders (drive side) should be set and tested first, followed by the roll set at the operator side.

To keep the changeover time to a minimum, each set of rolls should have its own entry guide and straightener. If the product is curved (swept) after the operation, then two individual curving units

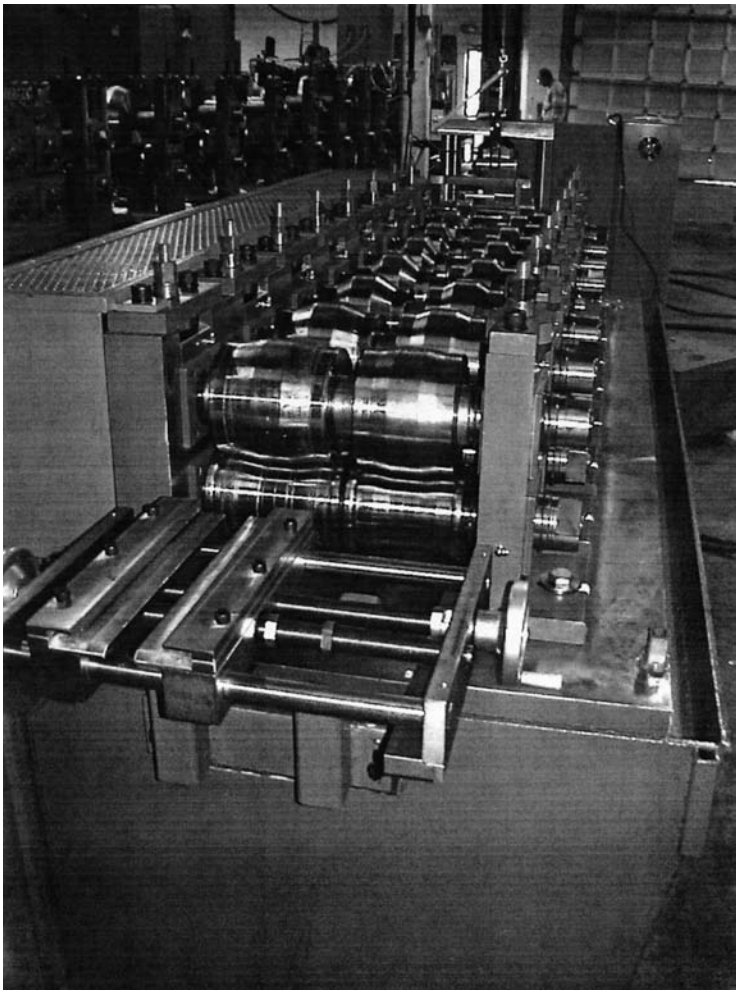


FIGURE 2.23 Side-by-side rolls on a mill.

are recommended for the sections. If the prepunching has a different pattern, then either quick-change die should be used or the dies should be capable of moving sideways. Either the complete cutoff die or the cutoff die inserts should also be of the quick-change type.

Considering the advantages of the quick changeover, some customers are requesting to install three sets of rolls on the same shaft. Obviously, the longer the shaft is, the more critical the shaft deflection will be. The recutting requirements (all sets have to be recut at the same time regardless of unequal wear) and the number of additional stands to allow individual adjustments should also be considered. Three sections with relatively loose tolerances may be tooled on common shafts, but the optimum is to have only two sets of rolls on the shafts.

Occasionally, it is requested to install four, five, or six sets of rolls on the shafts. This arrangement is not recommended.

Special side-by-side rolls are used in the lines that roll form two products at the same time from one common strip. The common strip is slit into two at one point in the line. This system is used to increase productivity to make two identical, or one left and one right section with each cut.

If three, four, five, or more sections have to be roll formed, or if the sections are too wide to be placed economically side-by-side in one stand, then a “side-by-side stand” mill can provide the solution for quick

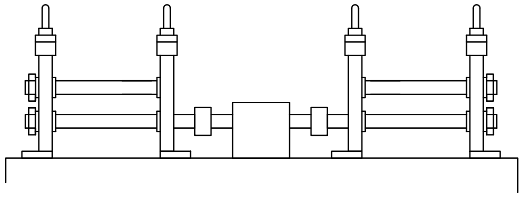


FIGURE 2.24 Side-by-side stands on a common mill base.

changeover (Figure 2.24). In the side-by-side stand mill, the common drive is usually at the center of the mill bed. The drive to each side can be disconnected to avoid accidental start. Disconnect is usually automatic or mechanical, not manual.

Using side-by-side stands, one set of tooling can form products, while the other (disconnected) stands can stay idle or the rolls can be changed. The changeover of the two sides is quick, taking only a few minutes.

If the sections are wide, then the two mill beds can be attached side-by-side (Figure 2.25). This arrangement can be taken a step further and the stands on both sides can be on rafts. Rafting will reduce the changeover time of the rolls. However, with such a complex arrangement, the cost-effectiveness should be checked. It is possible that two separate mills will provide better flexibility, productivity, and perhaps a lower overall cost.

2.2.8 Pull-Through Mills

Roll forming mills can have nondriven forming rolls. Most side-roll stands and often the top shafts are not driven. On rare occasions, none of the shafts/rolls is driven. In the latter cases, the strip is pulled through the mill by other means while the idle (nondriven) rolls are doing the forming.

When forming thin material (e.g., 0.003 to 0.020 in. or 0.075 to 0.5 mm) in small mills, the strip can be pulled through by a "caterpillar" belt, winder drum, curving head, or by other means.

If a thin material is joined to a thicker roll-formed section in their full lengths, then the mill, which forms the thick material, can pull the thin material through a separate nondriven mill. This method is sometimes used in ceiling gridlines to join the prepainted "cap" to the galvanized structural part (Figure 2.26).

Pull-through roll forming has limited applications but it has other great potentials. It can provide straight sections with better cross-sectional tolerances than other methods (see also Chapter 15).

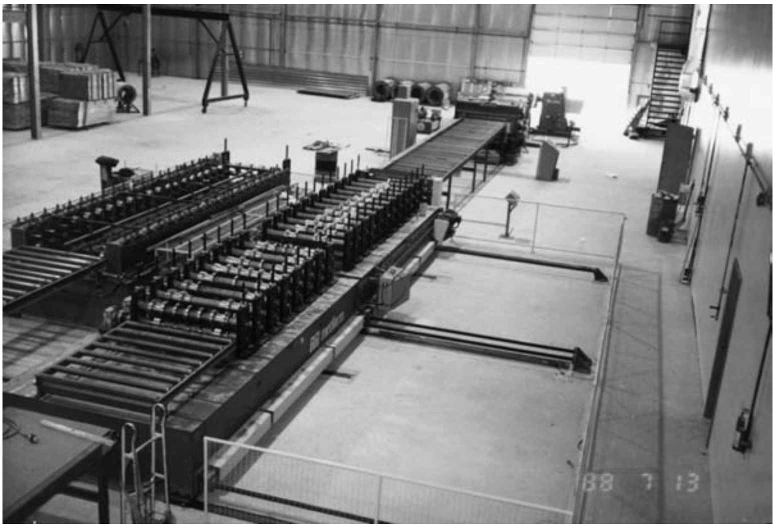


FIGURE 2.25 Side-by-side panel mill. (Courtesy of Metform International Ltd.)

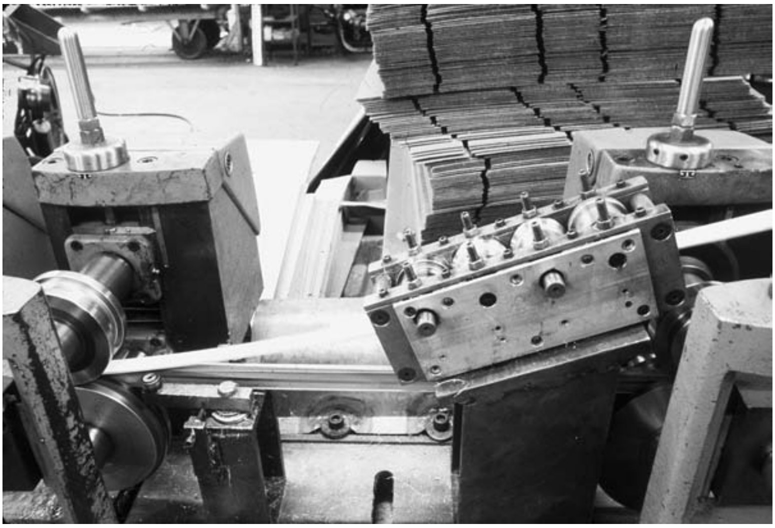


FIGURE 2.26 Nondriven, pull-through mill.

Thicker materials, such as 0.060 to 0.100 in. (1.5 to 2.5 mm), require more pulling force. Pairs of driving rolls located between each idle forming roll passes can produce structural "U," "C," "Z," and other sections. Profiles within the limits can be changed quickly by exchanging the idle profile forming rolls only.

2.2.9 Spiral-Tube Mills

Corrugated spiral tubes with lock-seamed, welded, or other joints are used for rigid culvert pipes, flexible water/electrical hoses, and other applications.

The corrugated section is formed in a mill (Figure 2.27) and curved with a special curving head (Figure 2.28). Most frequently, the edges are lock-seam joined continuously in the curving head (mechanical joint) or they are welded.

The diameter of the finished tubes/pipes is changed by altering the "helix angle" (the angle between the entering profile and the exiting tubular product), without changing the width of the roll formed section. Usually, the curving head and the run-out table remain in a fixed position, and the helix angle is changed by "swinging" the mill bed around a pivot point, which is located at the curving head.

The same principle is used in the manufacturing of smooth wall lock-formed (or welded) ventilation pipes. For light gauge ventilation pipes, the spiral tube curving is often accomplished with "bronze shoes." In this case, each diameter (and helix angle) must have its own shoes.

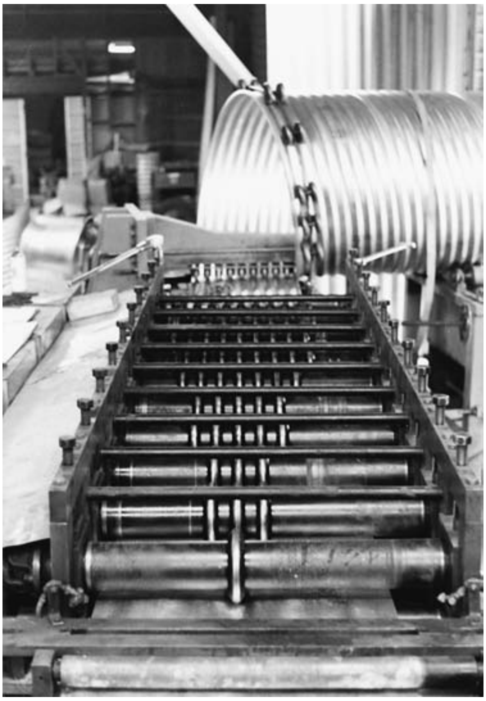


FIGURE 2.27 Corrugated spiral-tube (culvert) mill.

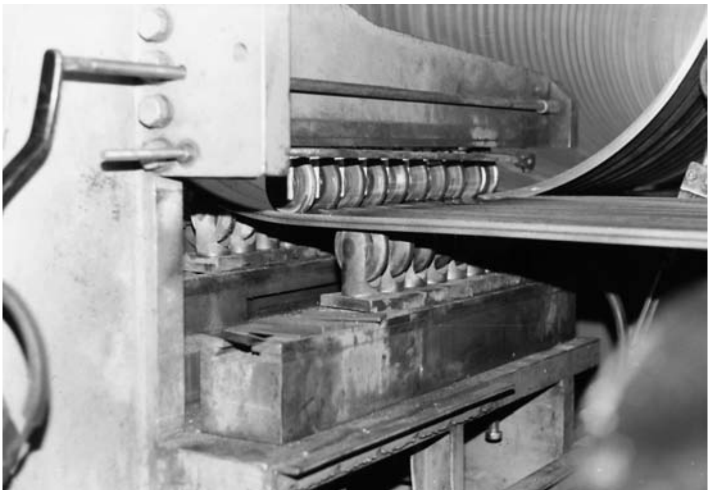


FIGURE 2.28 Curving head of a spiral mill.

2.2.10 Truck-Mounted Mills

Installers of construction products occasionally find it necessary and often more economical to form the products at the job site.

For example, to reroof an existing building, the architect may specify over 100-ft (33-m) long sheets. Because transporting and handling these sheets from the plant to the job site is not practical, it is easier to move the complete line to the job site.

Most special, trailer-mounted lines have their own diesel generator, hydraulic or other drive, cutoff press, and an uncoiler that can be loaded from ground level (Figure 2.29).

These self-contained units are also used in less developed countries or at any place where, owing to the lack of proper infrastructure, it is easier to transport the equipment in one truck and the coils in another one than to ship many truckloads of finished products.

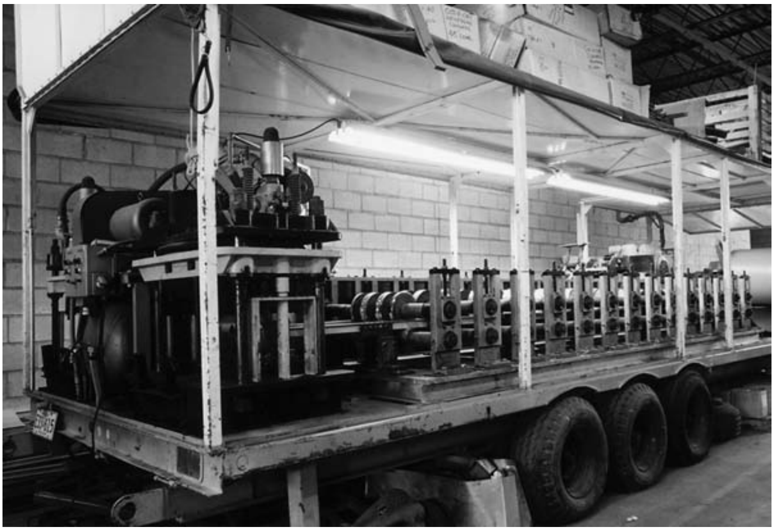


FIGURE 2.29 Trailer-mounted roll forming line.

Several types of truck-mounted units are used by contractors for job site manufacturing of eavestrough, sidings, soffits, and similar products. These units usually have a "plug-in" electrical motor drive. Small items such as eavestrough are often manufactured in a "stop-and-go" operation, and the products are cut by a manual shear mounted at the end of the mill.

2.2.11 Special Mills

A variety of special application or "homemade" mills are in use by the industry. Many of them do not fit into the previously mentioned groups, but they work satisfactorily. Several of these homemade units are eventually replaced with better quality or higher output, standard, commercially available lines. However, the lack of experience eliminates many preconceived ideas and homemade roll forming lines often incorporate ingenious methods of roll forming.

2.3 Mill Components

2.3.1 Mill Bed

The mill base, sometimes called "bed," supports the stands, shafts, rolls, drive train, and the components needed to form the sections. The most important requirements for the base are:

- Rigidity during operation, transportation, and installation
- Smooth, leveled top surface for installation of the components
- A keyway or other component to be used for aligning the stands
- Drainage for the roll forming lubricant

Long mill bases may have to be split into two or more sections to accommodate machining, handling (lifting), and transportation. If the base is split, if extension is anticipated, or other units are to be attached to it at a later date, then additional plates and joining fixtures have to be mounted to the joining end(s) of the mill bases.

Mill bases must be capable of accommodating recirculated lubricant used during forming. In the case of split bases, attention has to be paid to providing recirculation to each base section and to making a watertight joint between the bases.

In most cases, the base also supports the drive train. The gear boxes that drive the stands are very seldom mounted on a separate base.

Standard mill base design does not exist, but most beds are similarly constructed either from plates or from tubular sections. A typical bed made from plates is shown in Figure 2.30. The upper surface of the top plate is either fully machined or is machined only along the longitudinal edges where the stands and gear boxes are mounted. An alignment keyway is machined in the full length of the top plate. The keyway (or other components) should be straight within 0.001 to 0.002 in. (0.025 to 0.050 mm) along the full length of the mill even if it is assembled from sections. Holes are drilled and threaded for mounting the stands and other components. The upper edges of the base sides are welded to the top plate, and the lower edges are attached to a frame structure. Leveling and foundation plates are attached to the frame. Cross-plates and other members welded into the cavity of the base provide additional rigidity and support.

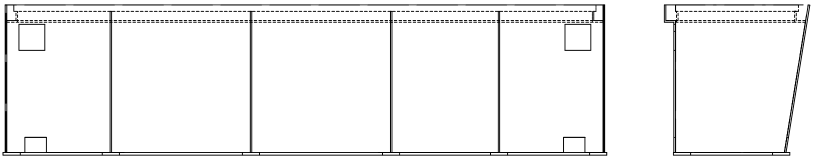


FIGURE 2.30 Roll forming mill bed.

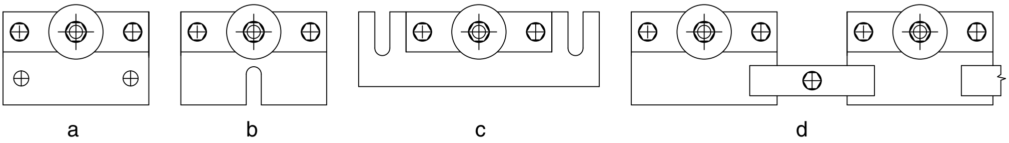


FIGURE 2.31 Different methods to fasten the outboard stands to the mill base.

To provide a return flow to the lubricant, most mills have a channel around their top perimeter. Frequently, the channels are made from structural angles welded to the bed with a sufficient gap for the lubricant and access for cleaning. It is useful if the bottom of the channel is slanted towards the liquid discharge opening. During construction, the top of the outside vertical leg of the angle should be above the mill bed. The protruding leg machined to level with the mill bed provides an additional support to the outboard stands during tool change and installation.

The basic requirements for structural or tubular frame construction are the same as for plates. If the bed does not have a continuous top plate, then a thinner lubricant collector-plate can be utilized.

Special consideration should be given to the motor/gear/drive train supports. If the top plate is cut out around the center of the mill to provide space for the drive belt or chain, then the rigidity of the base should be rechecked. The cutout may have to be reinforced.

In mills traveling sideways on rails, proper support should be provided for the casters (or slides) and the forces exerted during the sideways movement should be checked.

In most cases, the height of the mill base is calculated to provide comfortable pass line height for the product. Usually, the pass line height is set at 36 to 40 in. (900 to 1025 mm) above the floor. However, the size of the stands, the type of presses, other secondary operations in the line, and the method of material handling may determine the actual pass line height. If the pass line height is too high, then a walking/working platform must be provided along the operator side of the mill. However, safety and fatigue (the frequency the operator must step on and off the platform) are additional factors to be considered. Therefore, occasionally, the cutoff press or other equipment is installed in a pit to create a comfortable pass line height for the operators.

2.3.2 Stands

In most cases, the drive-side stands are exposed to considerable forces and bending moments.

The operator-side (outboard) stands are exposed to lesser forces. They usually support the shafts through needle bearings and long bearing sleeves. As a result, there are no forces acting on the stand in the axial direction of the shaft. The outboard stands are fastened with one or two bolts to the mill base (Figure 2.31a–d). The latter two (Figure 2.31c,d) take the shortest time to remove and install the stands. The vertical forces are contained by the vertical legs of the stands. The forming resistance, the uncoiler brake, the changing roll perimeter speeds, and occasionally the jamming of the strip create horizontal forces in the direction of strip travel. These forces are accentuated by torque of the drive train. To withstand the resulting stresses, the drive-side stands must be sturdy and well anchored to the mill base. Both side stands have to be sturdy enough to withstand the shafts separating forces. These forces are occasionally multiplied by incorrect setup (too much pressure applied by the operator) or mishaps such as double or triple strip thickness, or foreign materials forced through the rolls.

Large forces bending the shafts increase the shaft deflection (the shaft's center-to-center distance at the middle of the shaft). Excessive shaft bending can change the cross-section of the product, especially in the case of long roll spaces (shaft lengths). Excessively high forces can bend the shafts permanently. Permanently bent shafts will change the product dimensions at every revolution of the shafts.

To avoid costly downtime and repair of bent shafts, some suppliers provide limited strength crossbars at the top of the stands. These crossbars have been designed to break before the shafts permanently bend. However, changing the crossbars is also time consuming. An alternative method is to use calibrated

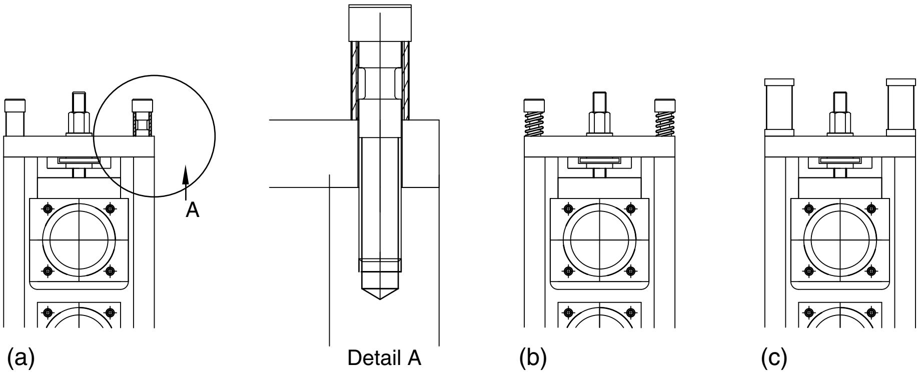


FIGURE 2.32 Using calibrated strength screws or springs or pneumatic/hydraulic cylinders can prevent permanent shaft bending.

strength screws to fasten the crossbars to the stand. These screws act as "shear pins" (Figure 2.32). However, the simplest solution to avoid shaft bending is to use an elastic top shaft (bearing block) hold-down mechanism such as preloaded springs, or pneumatic or hydraulic cylinders (see also Section 15.2.6).

A drawing of a typical stand is shown in Figure 2.17. Most roll forming mills made in North America have the bottom shafts in a fixed position above the mill bed. The top shafts can be adjusted up and down with screws. To allow easy and accurate adjustability of the top shaft, the lifting/pushing screws above the bearing blocks, and their attachments to the bearing blocks and to the cross bars, must be free of play, with gaps not exceeding 0.0005 in. (0.015 mm).

The bearing blocks should move freely up and down, but the gap should be sufficiently small, especially at the drive side, that when the operator-side stands are removed, the end of the shafts cannot be moved up or down by hand (Figure 2.33).

The approximate position of the upper shafts is shown on a vertical scale fastened to the side of the stand (Figure 2.18b). A more accurate up and down adjustment can be observed on the micrometer scale attached to the adjusting screws (Figure 2.2 and Figure 2.18b). The micrometer scales at both the drive and the operator side shall show the same number when the shafts are exactly parallel.

It is essential that all shafts should be set exactly at 90° to the direction of the strip travel during installation of the drive-side stands. The smallest angular deviation can create serious roll forming problems.

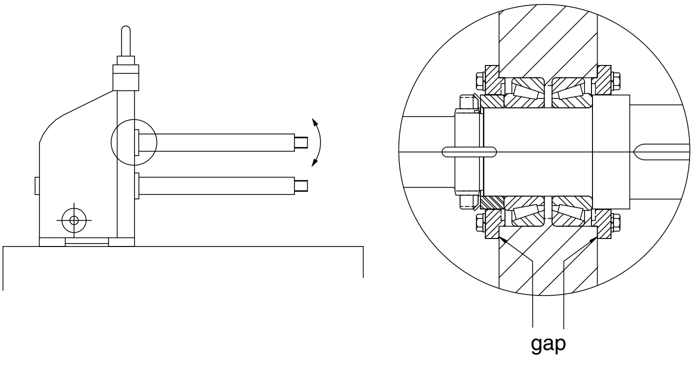


FIGURE 2.33 Gap between the bearing block and the stand should be small in order to keep the end of the shafts rigidly in position.

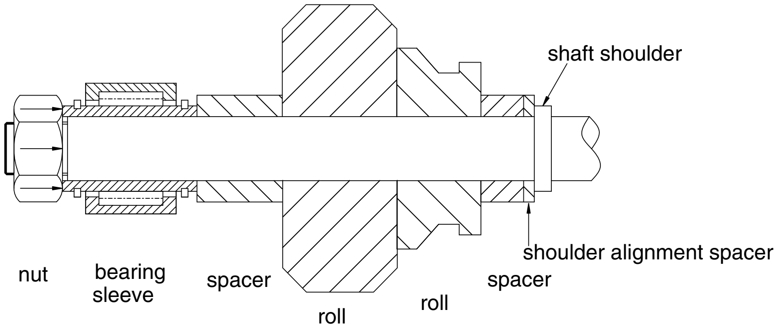


FIGURE 2.34 The nut at the end of the shafts pushes the bearing sleeve, rolls, and spacers against the shaft shoulder.

The drive-side stands are usually equipped with tapered bearings. The tapered bearings are taking both the vertical (shaft separating), and the axial loads. Wear in these bearings result in loosely held shafts. Loose shafts make it difficult, if not impossible, to set up the rolls accurately. Therefore, once the shafts become loose, tightening or replacing the bearings will be required, followed by shoulder realignment (see Section 2.3.9).

The operator side of the shafts is supported by needle bearings. The nut at the end of each shaft is pushing the needle bearing sleeve against the spacers and rolls which, in turn, are pushed against the shaft shoulder (Figure 2.34).

When the operator-side stands are removed, retaining clips at both ends of the long bearing sleeves are preventing the sleeves from falling out from the bearing blocks. When the stands are installed on the mill, the bearing blocks should be about at the center of the long sleeves, leaving more or less identical size gaps between the bearing blocks and the retaining springs (Figure 2.35).

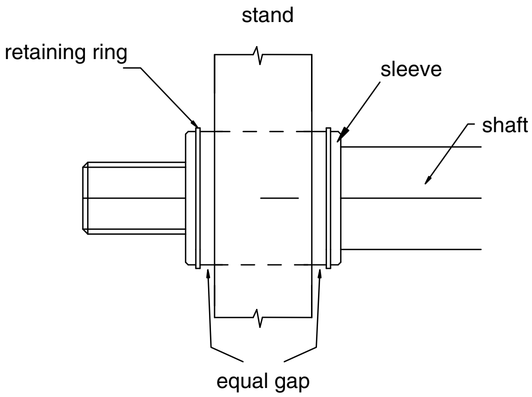


FIGURE 2.35 The bearing sleeves should be about at the center of the bearing block.

2.3.3 Shafts

The construction of the cantilevered shafts and the operator side of the two-end-supported shafts are similar. However, to save space, the rolls on the cantilever shafts are frequently held by the countersunk screws, threaded into the center of the shafts (Figure 2.36).

A typical linkage type gear-box stand is shown in Figure 2.37. Shafts can be driven by spur gears (Figure 2.38a–c), chain (Figure 2.39a), or universal joint (Figure 2.39b). In these cases, the top and bottom shafts can be identical except the operator-side threads at the end of the shafts.

Experience shows that if all threads are right-handed (RH), then the nuts either at the top or at

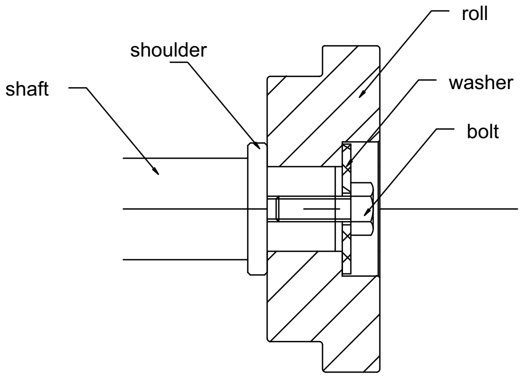


FIGURE 2.36 In cantilever mills, the rolls are often secured by bolts screwed into the shafts.

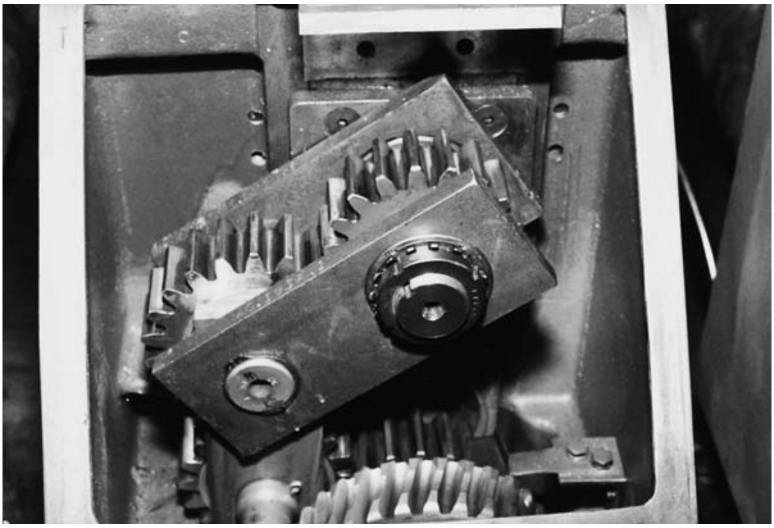


FIGURE 2.37 Typical linkage-type drive-side stand.

the bottom level shafts will become loose. To avoid this problem, all the shafts at one level have right-handed and at the other level left-handed (LH) threads and nuts as shown in Figure 2.40. The direction of thread is always opposite to the direction of shaft rotation; that is, if during roll forming, the shaft rotates counterclockwise, then RH nuts are required (tightened clockwise). If the shaft rotates clockwise, then the nuts must be tightened counterclockwise (LH thread). This requirement makes the mill unidirectional. In

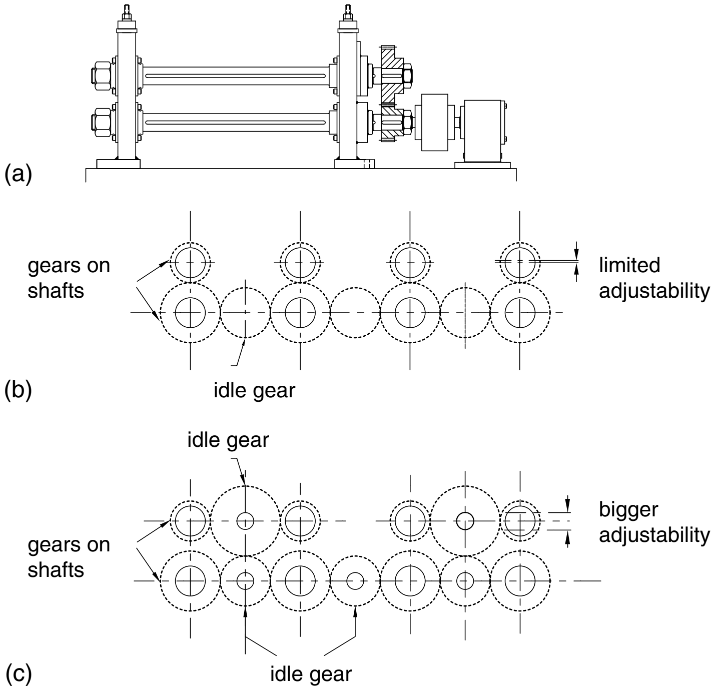


FIGURE 2.38 Typical gear driven stand (a); gear train with limited (b) and bigger adjustability (c).

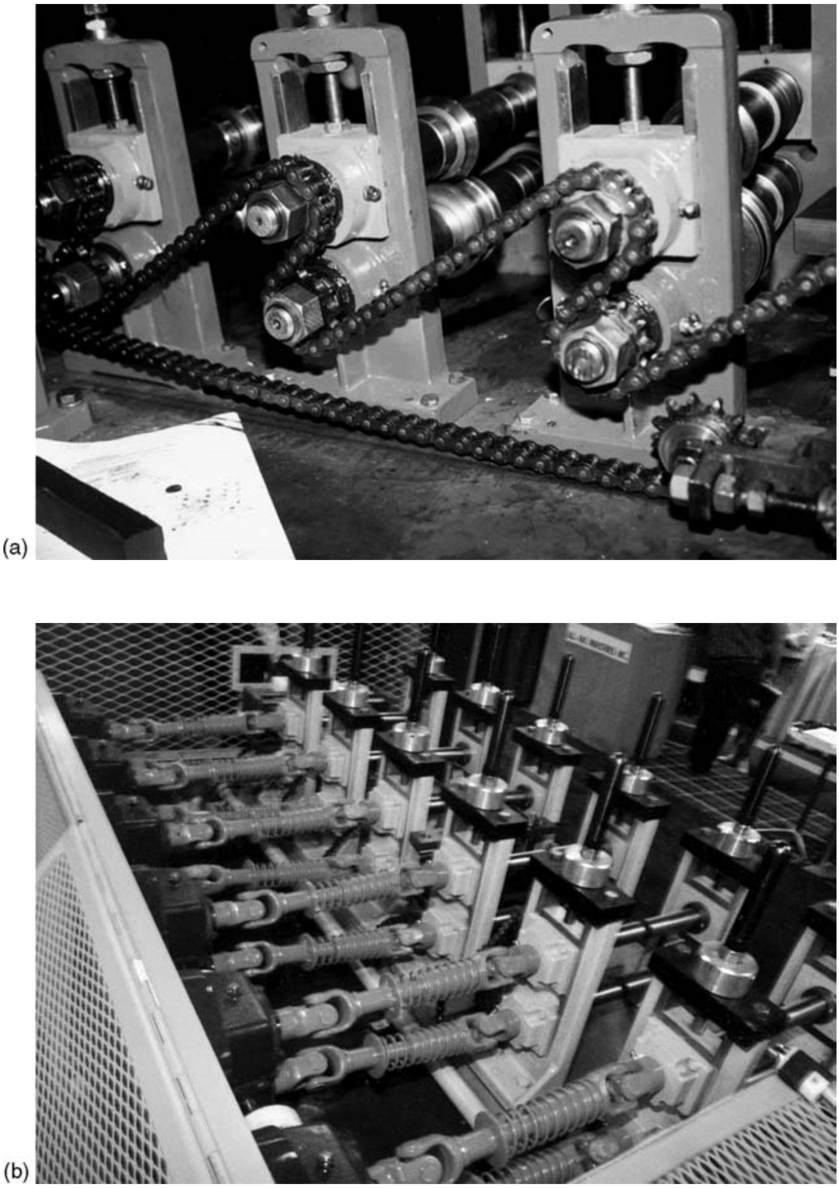


FIGURE 2.39 Chain (a) and universal joint (b) driven shafts.

other words, the mill (observing from the operator side) can run only from left to right, or from right to left. Lock nuts, hydraulic nuts, and other devices do not solve the problem if the mill is operating in the wrong direction.

The shafts can have fixed or variable roll space. The operator side of the fixed roll space shaft has a smaller diameter part that fits into the bearing (Figure 2.17). On variable roll space shafts, the ID of the needle bearings fit the shafts at any position (Figure 2.18). This allows moving the stand to different location along the shafts. Moving the operator-side stand closer to the drive-side stand reduces the shaft deflection, permitting to roll form narrower but thicker/higher strength materials.

The stresses generated by the axial forces and by the torque on the shafts are usually negligible. In very short shafts, the forces required to form the material, which separate the shafts, may create substantial

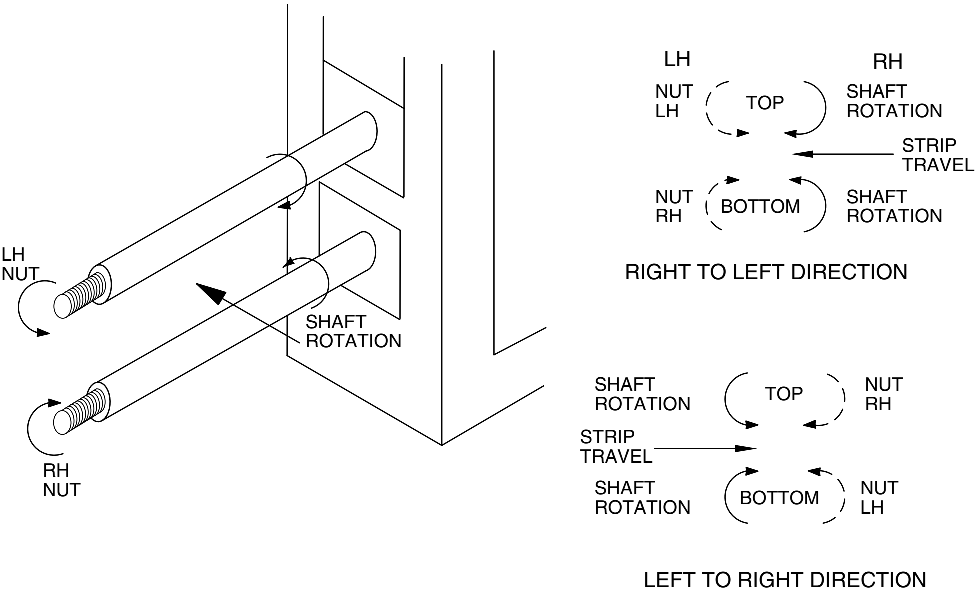


FIGURE 2.40 The thread at the end of the shaft is opposite to the direction of the shaft rotation.

shear stresses, but in most cases, these stresses are secondary to the stresses created by the bending moments deflecting the shafts. Therefore, practically all shafts are designed for limited bending (deflection). Bending above the permitted limit creates dimensional problems in the products. Normal use will not permanently deform the shafts, but abuse can cause problems.

The shaft diameters, selected for the specified applications, are a function of the thickness and mechanical properties of the material to be formed, the roll space (shaft length between supports), and by the type and number of bends made at each pass.

The selections of shaft diameters have been almost exclusively based on past experience. Equation 2.1 is the first attempt made by the author to calculate proper shaft diameters:

$$\mathrm{DIA} = 1.46\left[0.173\sqrt[3]{L} + 0.47 + 0.7\sqrt{t} \times \sqrt[6]{\frac{Y}{50}}\right]^4 \tag{2.1}$$

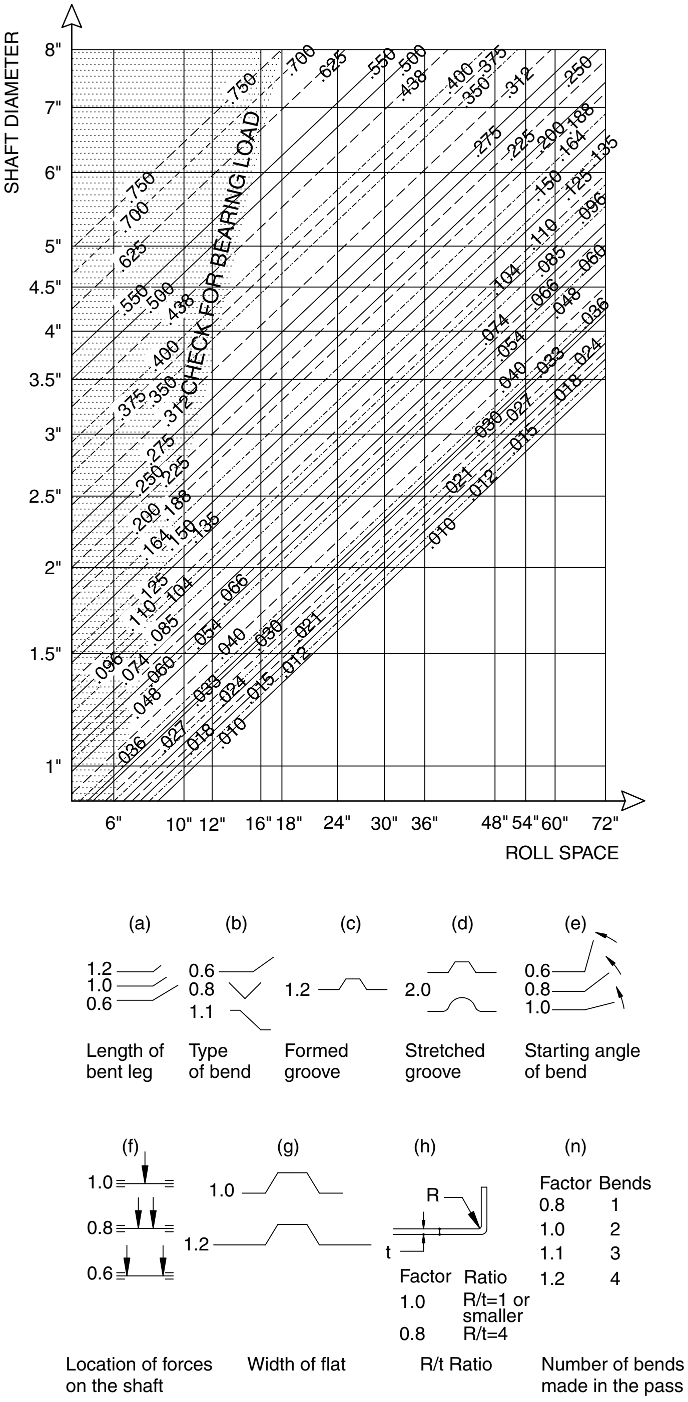
where DIA is shaft diameter; L, length of the shaft (roll space); t, material (metal) thickness; Y, yield strength on the material (DIA, L, t, Y are in imperial units).

Figure 2.41 shows a graph based on Equation 2.1. It is applicable to calculate shaft diameters for mills that roll form mild steel, with approximate 40,000 psi yield strength (275 MPa).

Equation 2.2 is an extended version of Equation 2.1. Additional factors such as the actual yield strength of the formed material, different types of forming, and others are included into the equation. These factors, to be used in borderline cases, are shown in the lower half of Figure 2.41.

$$\mathrm{DIA} = 1.46\left[0.173\sqrt[3]{L} + 0.47 + 0.7 \times a \times b \times c \times d \times e \times f \times g \times h \times n\ \sqrt{t} \times \sqrt[6]{\frac{Y}{50}}\right]^4 \tag{2.2}$$

where DIA is shaft diameter (DIA, L, t, and Y are in imperial units); L, length of the shaft (roll space); T, material (metal) thickness; Y, actual yield strength on the material the following factors are relative numbers, deviating from 1 depending on the severity of forming (see Figure 2.41); a, length of the bent leg; b, type of bend; c, formed groove (enter 1 if no groove is formed); d, stretched groove (enter 1 if no



Thickness used in the diagram = metal thickness (t) × a × b × c × d × e × f × g × h × n

FIGURE 2.41 Roll forming mill shaft diameter selector (in inches).

groove is stretched); *e*, starting angle of bend; *f*, location of forces on the shaft; *g*, width of flat section; *h*, radius/thickness ratio; *n*, number of bends formed in the pass.

Table 2.1 shows examples of shaft diameters calculated with Equation 2.1 or Equation 2.2.

The shaft diameter selection chart is based on limited shaft deflection. In the case of short shafts, where deflection may be negligible, the load carrying capacity of the bearings or shear strength of the shafts should be checked.

The diagram takes only the shaft deflection into consideration. Shaft deflection is only one criterion in the maximum capacity of a mill. Successful roll forming in a mill also depends on the construction of the mill, type of bearings, housing, maximum permitted torque at each pass, drive train, and many other factors. Therefore, a cross-section which can be successfully roll formed with one make of mill may not be formed on another mill with the same shaft diameter and roll space.

2.3.4 Power Train

Roll forming lines are usually powered by electrical motors. In a very few cases, mills are driven by hydraulic motors. Most hydraulic motors are powered by hydraulic pumps driven by electrical motors. Occasionally, the pump is driven by diesel engine, as with the case of truck-mounted lines working at remote job sites (Figure 2.29).

Most of the older type of roll forming mills were equipped with single speed AC motor. The power train usually consisted of a “V” belt drive from the motor to the mill and individual gear reducers for each stand. In low-cost models, chains or chain–gear combinations have been used for speed reduction and power transfer. Occasionally, a single speed gear-reducer box was installed between the electrical motor and the mill.

Eventually, different methods have been introduced to change the rpm of the drive shaft of the mill in order to meet with the demand of optimum roll forming speed such as high-speed forming of long sections and low-speed forming of short sections. In addition to the one- or two-speed AC motors, two-, three-, or four-speed gear boxes have been installed in the lines. All of these methods provided a specified number of fixed shaft rpm. To further optimize the roll forming speed, variable speed drives have been used in the drive trains. These speed reducers are either mechanical or occasionally hydraulic types with manual or electrical means of adjustment.

From the gear reducer or directly from the motor, the power has been transferred to the shafts at one location (at the front, at the end, or around the middle of the mill) or occasionally at two places (at the two ends, or about one fourth from each end). The transfer in cheaper units is conducted through chain, but most of the time, V or timing belts are used.

2.3.4.1 Chain Drives

Driving each individual top and bottom shaft with a continuous chain usually provides very little shaft adjustability, and the speed can be restricted (Figure 2.39a). An alternative method of chain drive allows greater vertical adjustability of the top shafts. Chains are considered a low-cost solution and usually they are not used in better quality mills.

2.3.4.2 Gear Drives

One possibility is to drive the shafts with a spur-gear train (Figure 2.38b). The problem with this gear arrangement is again the adjustability of the top shafts. Moving the top shafts up a small amount causes only the tip of the gears touching each other. This “out-of-pitch diameter” engagement does not provide a smooth drive and can easily chip or break the teeth of the gears. Moving the top shaft further up will disengage the top shafts. If the rolls are recut and the shafts have to be moved closer, then it is possible that the gear will restrict the downward movement. In some cases, forcing the top shaft gears into the bottom shaft gears will create a continuous “chatter,” which can leave marks on the strip.

A different gear arrangement — installing one idle gear between each top shaft gear as shown in Figure 2.38c — allows to adjust the top shafts 1 to 2 in. (25 to 50 mm) or more without disengaging the gears.

2.3.4.3 Mixed Drives

To reduce the cost of the mill, some companies occasionally combine chain drives with gear drives, or do not drive certain top shafts.

2.3.4.4 Nondriven Top Shafts

In the early mills, following the example of the steel mills, all top and bottom shafts have been driven. Later, custom roll formers and other users found that they could successfully roll form without driving the top shafts. Custom roll formers often have to use “nonmatching” roll diameters. The big circumferential speed difference can create problems if both the top and bottom shafts are driven. Eventually, some roll forming mills have been built without top drive. However, driving the bottom shafts generates only half the friction between the rolls and the strip. As a result, the first few passes often:

1. Cannot pull the strip into the mill
2. Generate large fluctuation in the product speed during forming
3. Cannot push the product through the straighteners, curving units, or other equipment

Therefore, in addition to driving the first one or two and the last one or two top shafts, mills are often supplied with nondriven top shafts, which can be readily equipped with spur-gears when required. It is usually the roll designer’s function, occasionally corrected by the setup technician, to indicate the intermediate passes that will require top drives.

2.3.4.5 Shaft Driven with Individual Motors

Mills have been built with a DC motor attached to each shaft. This method provides the maximum flexibility to any roll formers. However, owing to the relatively high cost, this method is seldom applied.

Single-speed AC drives are inexpensive, but they restrict the line to one speed and it makes the jog-in of the leading end difficult. The constant stop-and-go operation during jog-in (feeding the front end of the coil into each pass) has also some wear and tear effect on the drive train.

The introduction of the soft-starter makes the jog-in more operator-friendly. It is possible to set the rate of acceleration, which means that during the jog-in operation, the mill starts up slowly and usually does not exceed a comfortable speed. The variable speed or vector drives developed at a later stage make the application of most of the soft-starters unnecessary.

DC motors have been used for a long time to provide variable speed. In the 1950s and 1960s, eddy current motors were installed in some mills. By the 1990s, all manufacturers offered either DC or variable speed AC drives. In most cases, the price and occasionally special requirements such as constant torque, constant rpm, or high-torque at low-speed requirements are the determining factors in selecting the motors.

2.3.5 Side-Roll and Cluster-Roll Stands

In the early applications, roll forming was based on forming by the main passes only. If the result was unsatisfactory, then side-roll stands have been installed retroactively to “cure” the problems. Owing to time constraints and, frequently, financial restrictions, many of these side-roll passes consisted of only a pair of cam rolls fastened to welded angle frames. Frequently, these contraptions did the required job, but it was difficult to set up and adjust them. Therefore, side-roll stands have been looked down at by many people in the industry.

Side-roll stands, however, are an integral part of the equipment and tooling. Side rolls have several advantages. The shafts can be oriented at any angle instead of just being horizontal, as in the main passes. This flexibility allows locating the side rolls at optimum angles. With the exception of a few special cases

(Figure 2.42), side rolls are not driven. Therefore, they are less prone to mark or scuff the surface of the products.

The shafts of the side-roll stands can either be cantilevered or supported at both ends. There can be one, two, or more shafts with rolls forming or holding one bend line at one point (Figure 5.27, Figure 5.100, Figure 5.102a–f). These shafts are frequently not parallel to each other. The designer's decision about the type of shafts and their angles is usually based on local conditions.

Side rolls are excellent for forming the edges of the strips and are often preferred to the main forming rolls, especially when the formed "legs" or strip edges are close to vertical (close to 90° to the axis of the main shafts). Properly designed and easily adjustable side-roll stands are the practical ways to compensate for springback by overbending angles.

Because side-roll stands are just as important as the main stands, they should be designed to similar rigidity, precision, and adjustability.

Side-roll stands are usually fastened to the top surface of the mill base or raft. They can also be attached to the operator-side or the drive-side stands (Figure 2.43). Side rolls can be made adjustable vertically, horizontally, and in-between, or can be rotated around a bend line. The type and magnitude of adjustment depends on the functions of the rolls. To provide extremely accurate small adjustments, it is recommended that one adjusting and one "stop" screw for each direction of adjustment are used (Figure 2.44).

To promote ease of installation, the side-roll stand should be located with keys, after its alignment is tested. The same type and size of adjusting and locating screws should be used, thus allowing the use of a one-size Allen key wrench or other tool. The stands should have easily reachable lubricating points.

In certain type of mills, the small horizontal distance between the main rolls can make the installation and the adjustment of the side-roll stands difficult, even impossible.

If the roll designer finds it advantageous, then the side rolls can work at the main rolls. In these cases, the supporting structure must reach in between the top and bottom shafts (Figure 2.45 and Figure 5.105). These types of stands are called "cluster-roll stands." Once properly installed, cluster rolls seldom require adjustability in the vertical direction, but fine adjustment is needed in the horizontal direction, usually 90° to the travel of the strip (Figure 2.46).

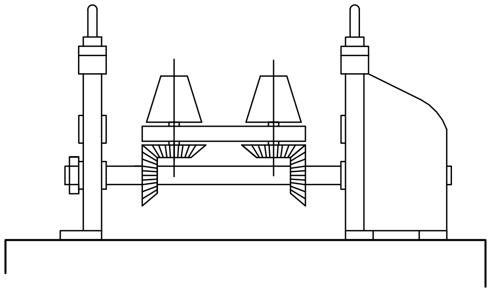


FIGURE 2.42 Driven side-roll stand.

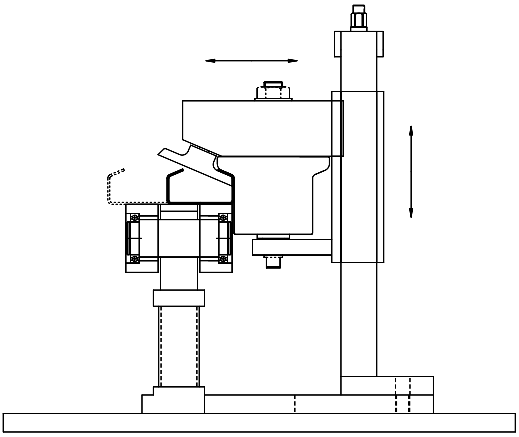


FIGURE 2.43 Side-roll stands attached to main stand.

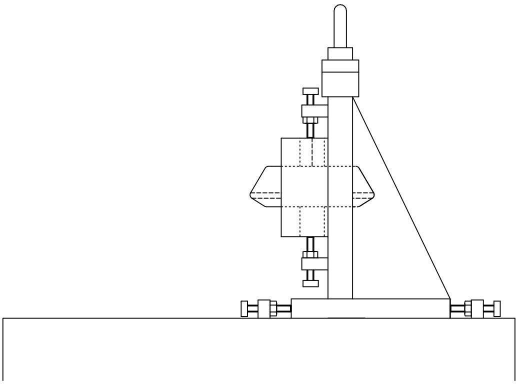


FIGURE 2.44 "Stop" screws help the fine adjustment of side-roll stands.

2.3.6 Guides Between Passes

The internal stresses generated in the section by the forming can frequently result in bow (downward or upwards), camber (sideways), twist, flare, or springback. These distortions can often be observed as the leading end of the strip exits from the passes. Strips with substantial cutouts, such as holes and notches, can display similar deviation from straightness and flatness. As an effect of these deviations, the leading edge of the strip does not always enter straight into the next roll, but hits the roll at some other place (Figure 2.47). Frequently, the operator has to manually push the leading edge into the gap of the next pair of rolls each time a new coil is fed into the mill. It is accepted by the industry that the leading ends are "jogged in" by the operator at a slow speed, usually in a stop-and-go manner. This method is time consuming and reduces the efficiency of the line. It is also unsafe because most operators attempt to guide the leading edge by hand just at the entry side of the rotating rolls.

Good roll design with a sufficient number of passes, large roll entry angles with large radii, and if required, guides between passes allows "threading-in" ("jog") the strip at full speed. Full-speed forming is always expected when parts are formed from precut pieces.

To achieve full-speed and safe threading-in of the leading edge of the coil, large fish-mouth openings are required at each restricted area such as straighteners and cutoff dies (Figure 2.48).

Proper guides between passes not only help to jog in the strip, but also prevent buckling it between passes. Buckling can happen occasionally when the first passes are pushing the material, while somewhere around the last passes, the speed is reduced or the passage is restricted in the straightener or at other obstacles. To prevent buckling of less rigid finished sections in front of the straightener and the cutoff press, the part is often guided at those locations.

The guides can be made from a variety of materials such as cold-rolled steel, heat-treated steel, bronze, plastic, or combination of the above materials, and cam or conveyor rolls. Occasionally, to prevent buckling, the operators will use a temporary solution of 2 × 4s, which may remain there as a permanent fixture.

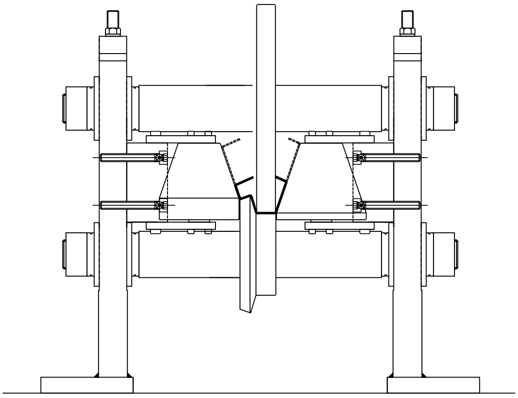


FIGURE 2.45 Cluster rolls.

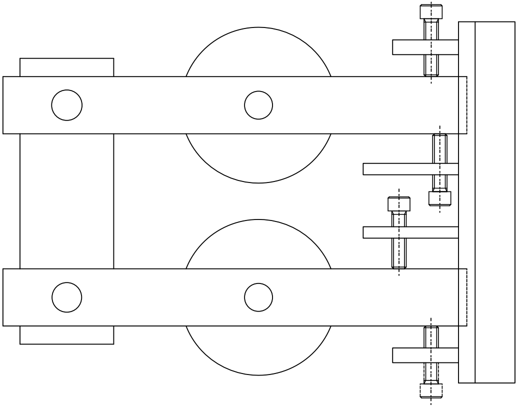


FIGURE 2.46 Fine adjustment of cluster rolls is required.

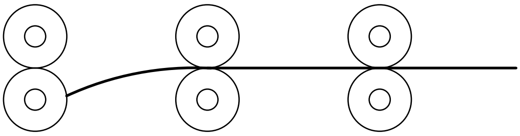


FIGURE 2.47 Internal stresses forces the leading edge of a strip away from straight line.

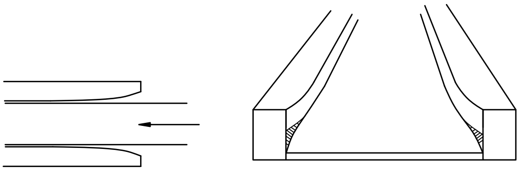


FIGURE 2.48 Large "fish-mouth" opening helps the entering of the leading edge of the strip.

It has to be noted that guides shall not be used to form the material. They are in contact with the strip or section only momentarily during the feed-in, but not during forming (Figure 2.49).

In the case of precut strips, and especially when the pieces are very short, full contact guides are required at the full length of the parts. Because of the variations in cross-sections, there are endless variations in the design of the guides.

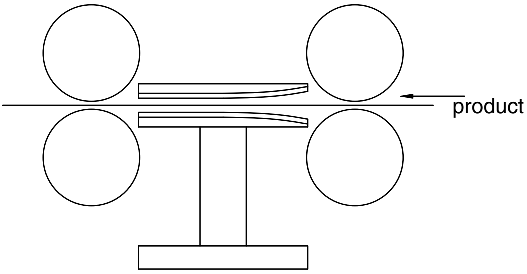


FIGURE 2.49 Guides help entering the leading edge into the roll are not in touch with the section during the rest of the forming.

2.3.7 Straightener

The internal stresses that are created by the roll forming process frequently bend or twist the products after exiting from the last pair of rolls. These deviations can be eliminated by a straightener unit installed after the last pass.

Wide building panels, with many straight bent lines, usually remain straight after roll forming, but most narrow and especially asymmetrically formed products require a straightener.

Based on the assumption that all problems, including waviness, will be “ironed out” by long straighteners, some of the early straighteners consisted of long (12 in. or 300 mm) tightly fitted bronze

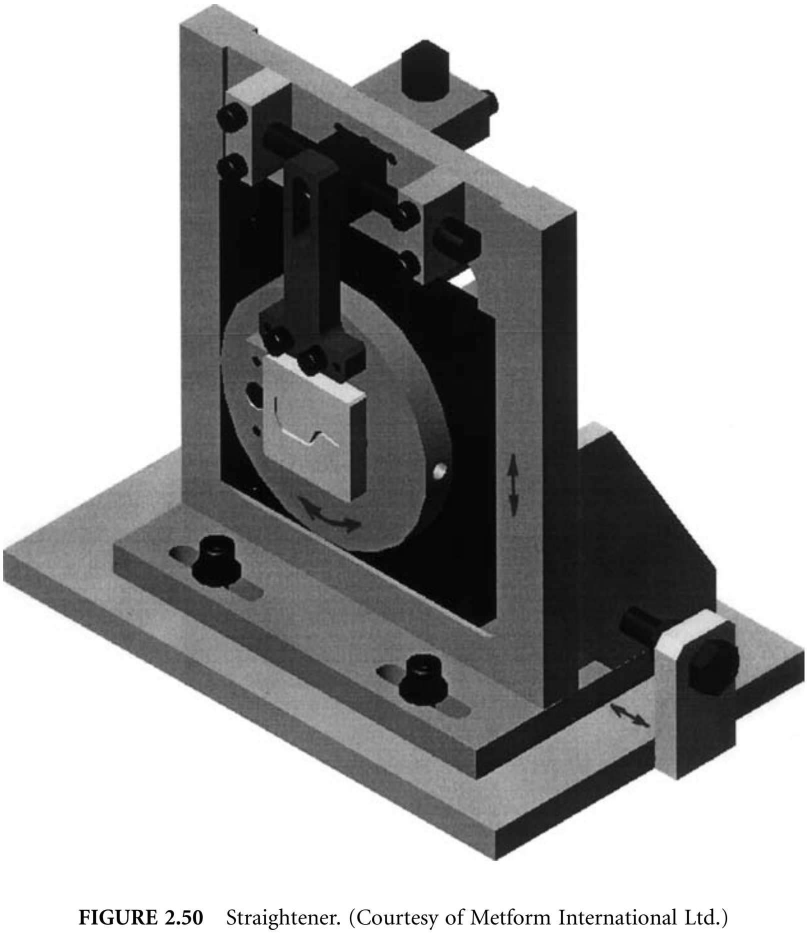


FIGURE 2.50 Straightener. (Courtesy of Metform International Ltd.)

blocks. This assumption is incorrect; the function of the straightener is to push the bend lines of the sections at the opposite direction of the deviation from straightness. Forces applied at the bent lines in a short distance are sufficient in almost all cases.

A straightener consists of a supporting structure and straightening tool(s) (Figure 2.50). The tool is either a "block" with a passage for the section or consist of rolls. In both cases, it is important that the tool reaches into the section and applies pressure on the bend lines. To correct the deviation from straightness of a bend line, the pressure is always applied to one direction at a time. Therefore, usually, a small gap can be left between the outside and inside tool surfaces (Figure 2.51).

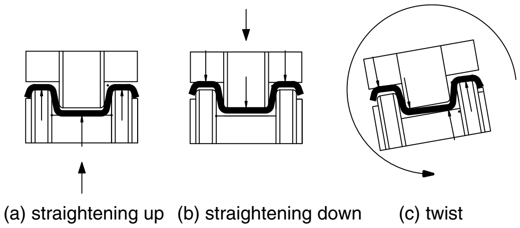


FIGURE 2.51 Straightener tool forcing the bend lines in one direction. The tool at the opposite end of the bend line does not have to be in contact with the material.

The straightener is usually located between the last pass and the cutoff die, as close to the last pass as possible. Wherever feasible, the straightener stand should move the blocks in a swinging motion instead of moving parallel up and down, or sideways (Figure 2.52).

If blocks are used for straightening, then they should have long, big fish-mouth opening to guide the leading end of the strip into the block at full speed. If required, additional guides can be applied ahead of the straightener (Figure 2.53).

It must be remembered that straighteners are not forming tools. During setup of the tooling, the forming rolls should be adjusted to roll the sections as straight as possible without a straightener. Once this is achieved, the straightener can be installed to correct the remaining deviation from straightness.

If the incoming strip has extreme camber or other deviations from straightness and flatness, then the internal stresses created during roll forming can be so high that even the best straightening device cannot correct these imperfections.

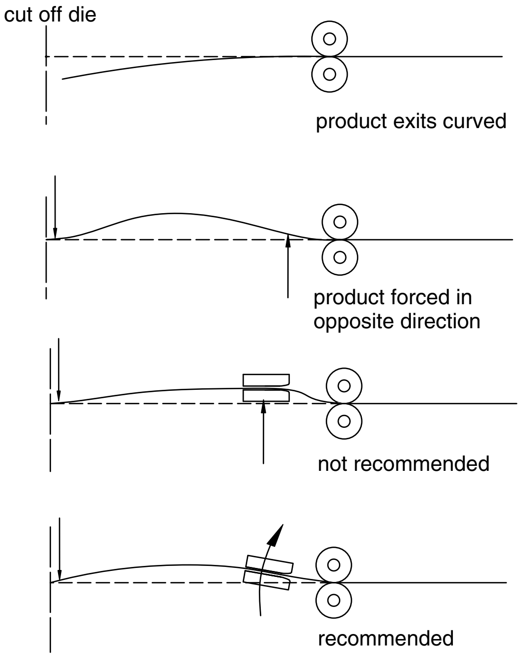


FIGURE 2.52 Moving the straightener blocks parallel up and down or sideways is incorrect. A swinging motion is better.

2.3.8 Lubrication System

Lubricants are used to reduce friction between the formed parts and the rolls, to eliminate the pick-up of zinc, aluminum, or other metals by the rolls, and to avoid scratching or marring the product surface. Lubricants are also used to wash away loose surface particles such as scale on hot-rolled steel. When thick materials are formed, lubricants are also used as coolant to dissipate the heat created by the forming. For details, see Chapter 7.

2.3.9 Shaft Shoulder Alignment

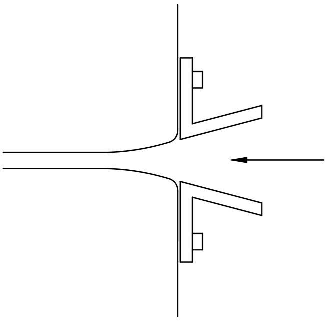


FIGURE 2.53 If required, additional guides can be applied at the entry side of the straightener and cutoff die to help entering the leading edge of the strip.

During roll design and roll manufacturing, it is assumed that the baseline of all rolls and spacers are exactly the same. During checking the finished rolls, the rolls and spacers are placed on a granite plate representing this baseline. The gap between the rolls is carefully checked in this position. If one imagines that this granite plate with the rolls is rotated to 90° so that the granite plate becomes vertical and the shafts horizontal, then in this position, the granite plate represents the location of the shaft shoulders, against which the rolls are rested. If in the mill, the shaft shoulders are not aligned, then the rolls cannot be properly aligned. Unfortunately, this is the case in a large proportion of mills currently in operation.

During forming, the shaft bearings wear and the shafts become looser and looser. When the operator side of a shaft can be moved easily up and down, then the shaft and its shoulder usually can also move in and out. Loose shoulders cannot be used for accurate roll positioning. To correct this situation, the tapered bearings can be tightened by pulling the shafts towards the drive-side direction. This also means that the shoulder moves towards the drive side. If new bearings are installed, then the shoulders are frequently moved outwards, towards the operator side. Therefore, a mill that was assembled with accurately aligned shoulders can be out of alignment within a few years. Wear in the bearing blocks and stand interface can also contribute to shaft shoulder misalignment.

Different methods are used to align shoulders. The most frequently used method by the author to align shoulder is described in Chapter 10 (Section 10.3.9).

2.3.10 Installation of Other Units in the Mill

The roll forming base is frequently the most convenient place to install other units or equipment for the secondary operations. These units can be positioned ahead, in-between, or after the roll forming stands. If the unit is large, the horizontal center between the stands can be enlarged, or the mill bed can be extended before the first or after the last pass.

It is assumed that all additional operations are continuous (do not require to stop the section). Such operation can be rotary punching, rotary embossing, welding, curving (sweeping), and others. Hydraulic presses, which do not generate shocks, can also be mounted on the mill bed. However, mounting mechanical or pneumatic presses on the mill bed is not recommended.

If the secondary operation requires coolant or liquid other than the one used for roll forming, then a separate drainage and lubrication system has to be installed. Proper alignment of all additional equipment and tooling is as crucial as the alignment of the forming rolls.

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3

Presses and Die Accelerators

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George T. Halmos
Delta Engineering Inc.

3.1 General

Roll forming lines, unless they are fed with precut blanks, require an equipment to cut the strip or the product to length. The cutting-to-length process can be ahead of the roll forming mill (precut), in-between the forming stands or mills, after the roll forming mill, or after the last "in-line" operation (e.g., punching or curving). Presses are the most frequently used equipment for cutting. Occasionally, shears are used for precutting and saws, lasers, plasma jets, or other methods for postcutting. Rotary devices can be used for both pre- and postcutting.

Presses are also used to punch, notch, emboss, bend, coin, or mark the products. Most frequently, mechanical, pneumatic, or hydraulic presses are employed in the lines. The presses are actuated intermittently by signals. The signals may be generated by a strip feeder, encoder, or other length measuring device, hole or cutout sensor, flying die, or other devices.

3.1.1 Press Capacity

The capacity or "tonnage rating" is the maximum instantaneous or continuous force the press can exert through the dies on the workpiece.

The capacity of the crank-shaft-operated mechanical presses is usually rated at 0.125 in. (3 mm) above dead bottom center (DBC). For details, see Section 3.2.

The capacities of the pneumatic presses (Section 3.3) are usually the sum of forces created by the pneumatic cylinder or air tubes and the inertia of the fast moving heavy ram.

The capacity of hydraulic presses (Section 3.4) is traditionally established by the force generated by the cylinders (cylinder area multiplied by the hydraulic pressure).

3.1.2 Common Press Parts and Definitions

The most common terminology used for presses in the roll forming lines is listed below (see also Figure 3.16 and Table 3.1 and Table 3.2):

- *Length* of the bed is usually identified as R to L (right to left) or L to R in the direction of the strip travel. The length should accommodate the die and, in the case of flying die, the space required for the die home position, acceleration, deceleration, and safety overtravel. (Press shops traditionally call this R to L or L to R dimension as width of the bed.)
- *Overall Width* (W_o) of the bed, F to R (front to rear), is the bed dimension perpendicular to the strip travel. (This dimension is seldom used in specification.) (Press shops traditionally call the F to R dimension as depth.)
- *Distance between posts across the strip travel* (W) is the dimension between the posts or other post components that limits the maximum width of the die.
- *Distance between posts along the strip travel* (W_L) is the dimension between the post or other post components.
- *Bed and ram deflection* is critical to die life. In conventional presses, the deflection is usually limited to 0.0015 in. per 12 in. (0.04 mm per 300 mm) when the maximum tonnage is applied to the center two thirds of the press bed. The rule is more liberal for presses designed for roll forming lines. In the case of flying dies, the strength of the rail and the rigidity of the die are important factors in restricting the deflection. For shearing or punching, the deflection of the press bed can be less critical, but special care should be taken for embossing or when the bed is weakened by a scrap (slug) discharge cutout.
- *Die Space* is the combination of the distance between the posts across the strip travel and the bed width. It specifies the maximum width of a die, which fits between the post and the length requirement. In the case of stationary die, the press bed length (R to L, or L to R) can be equal to or larger than the length of the die. For flying die, the bed length is equal to or larger than the die length plus the die travel plus the safety distance for overtravel. The die travel includes the distances required for acceleration, press action, deceleration, and safety.
- *Stroke* is the travel of the ram (head). The press stroke is a fixed length in most crankshaft presses. It is adjustable in pneumatic and hydraulic presses. The stroke of small mechanical presses is usually around 1.5 to 2.5 in. (40 to 65 mm) and of larger presses is 2 to 4 in. (50 to 100 mm). In special cases, the stroke can be larger but very rarely exceeds 6 in. (150 mm).

  The stroke of pneumatic press is relatively short (0.375 to 2 in. or 9.5 to 50 mm). The stroke of the hydraulic presses can be easily adjusted to the smallest required for the operation, but the press has to have the capacity for longer strokes to facilitate tool changes and die adjustments:
- *Throw* in mechanical presses is half the stroke.
- The *base* supports the press. The base can be fixed or adjustable in the vertical or horizontal direction. If required, the base can also be tilted or swung (see "Adjustability of the Press" in this section).
- The *bed* holds the die or the die rails and posts. The bed and the base are often built as a common unit.
- *Posts (pillars)* or occasionally *frames* connect the ram to the base.
- The head, frequently called the "slide" or "ram," is the moving part that exerts force on the die.

The position of the head (distance from the bed) is often adjustable.

- *Shut height* is the distance between the top and bottom rails (or between the bed and the head if the press has no rails) when:
    1. The head is adjusted to the top position.
    2. Stroke is down (bottom position).
- *Die slides* attached to the die shoe(s) guide the flying die. To reduce friction, usually brass (or bronze) plates (Figure 3.1 and Figure 4.26) or spring loaded rollers are used on the surface of the die slides where they are in contact with the hardened die rails.
- *Die rails*: the flying dies are supported and guided by hardened steel rails attached to the press. A large variety of rail designs are used by the industry.

  The bottom rails guide the dies during its full length of travel. If the top die is lifted up by the head (slide), then the upper die rail is constructed to guide and lift the upper part of the die.

  In the case of “spanking” dies, only the bottom part is guided. The downward movement of the head presses the top die part down and it is lifted back to its original position by springs (Figure 4.27).

  The die rails are made from hardened steel and are bolted to the die bed. The horizontal gaps between the die rails and the slides are usually not more than 0.002 to 0.005 in. (0.05 to 0.12 mm).

  To make die change easy, the rails at the exit side of the press can be extended long enough to support the die when it is pulled out from the press (Figure 3.2).
- *Linear bearings*: flat linear bearings often replace the die slides and die rails. They are most frequently used in low impact conditions such as hydraulic presses (Figure 3.25 and Figure 4.28).
- *Strokes per minute*: practically all roll forming line presses work intermittently. The strokes per minute number indicates the maximum number of strokes the press can exert under normal operating conditions. In mechanical presses, the stroke per minute is usually limited by the clutch and the brake system.

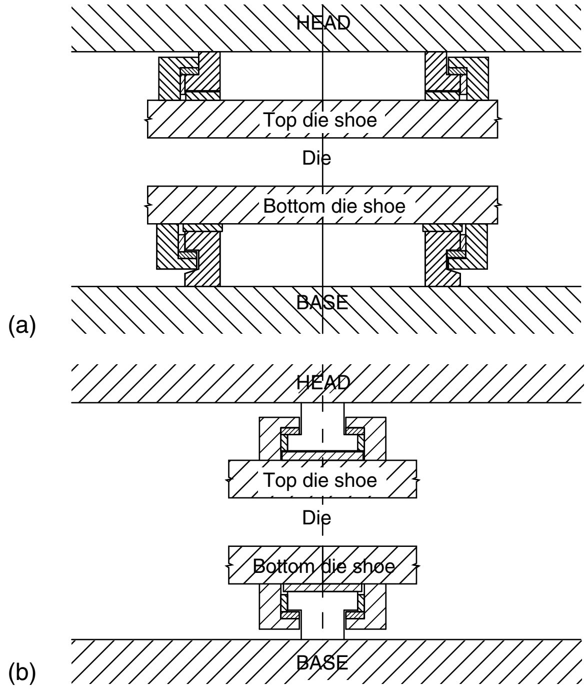

FIGURE 3.1 Typical die rails and die slides for most dies (a) and small dies (b).

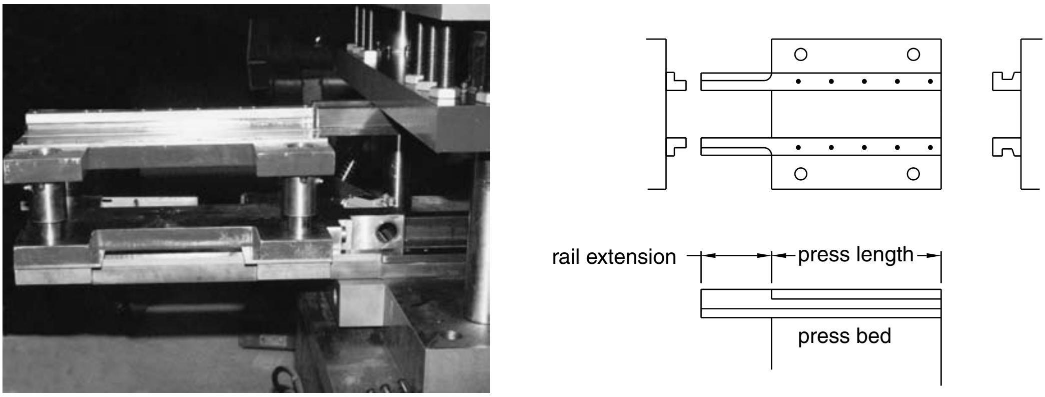

FIGURE 3.2 Bottom die rail extension can support the die outside the press during die exchange.

The restricting factors for pneumatic presses are the stroke length, the availability of air, and the time required to fill the air cylinders (or tubes), to release the air pressure, and to lift the ram up to the home position.

In the case of hydraulic presses, the volume of the cylinder (piston area × working stroke length), the capacity of the hydraulic power pack, and the valves constrain the maximum number of strokes per minute.

- *Scrap (slug) chute* is incorporated in the prepunching and many cutoff presses. Instead of using high die risers and belt conveyors to remove the scrap, the press beds are cut out. The slugs and cutouts fall through the holes into a scrap chute that guides them into a scrap collecting box located outside the base (Figure 3.11). The scrap box should be easily reachable, but should not interfere with the movements and safety of the operator.
- *Press Pass Line* is at the same height as the pass line above the mill bed, but it is measured from the plant floor.
- *Adjustability of the Press*: depending on the type and construction of the press, the following can be adjusted:
  - Capacity
  - Stroke length
  - Stroke per minute
  - Shut height
  - Pass line height
  - Press location perpendicular to the strip travel (front to back direction)
  - Angle and location of the press base in the horizontal or vertical direction to suit curved (swept) sections

3.1.3 Impact, Vibration, and Foundation

- *Impact*: all presses create an impact when the velocity of the moving parts changes. The impact depends on the type of the press (mechanical, pneumatic, or hydraulic), the acceleration or deceleration, the weight of the moving parts, the force required to punch, notch, or form the metal, the die configuration, and other factors.
- *Vibration*: Vibrations are generated by the imbalance and inertia of the moving parts of the press and the impact generated by the interaction of the moving parts and the material.

Heavy vibration can loosen bolts, damage press parts, and shorten die life. Vibration transmitted to the air is the main source of the press noise. Vibration transmitted to the floor can create damage to other equipment on the floor, including electrical and electronic parts of the line, and also cause discomfort to the operators.

The heaviest vibration and loudest noise is created by the air presses, followed by the mechanical presses. Hydraulic presses generate the least amount of vibration and noise.

The vibration and noise created by the breakthrough can be reduced by proper tool design, such as applying rake angles and slightly staggered punches (Figure 3.3).

Damping can reduce press vibration transmitted to the floor. Effective damping can be achieved with vibration resistance elastic materials, metal springs, or air springs. Reducing vibration usually also reduces the noise level. Noise can be further reduced by press or die enclosures.

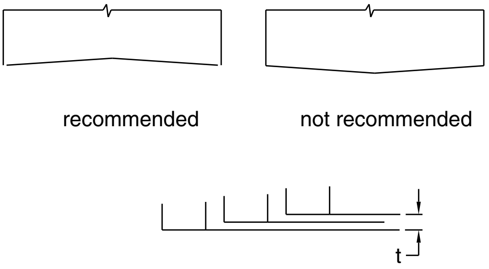

FIGURE 3.3 Rake in the punch and staggered punches reduce the force, noise, and vibration.

- *Foundation*: The constant pounding of the presses not only vibrates the floor, but can also compact the soil underneath the floor, cracking the floor, and possibly "sink" the press. Therefore, separate foundation blocks are recommended under heavier mechanical and air presses. These foundation blocks solidly support the press and do not transfer vibration to the floor from which they are separated by elastic insulation.

The size of the foundation block depends on the capacity, type, bed size (foot print) of the press, and the soil condition. Although some press suppliers provide guidelines for press foundation (Figure 3.4), the actual size of the foundation has to be established by the contractor who must take the local soil conditions into consideration.

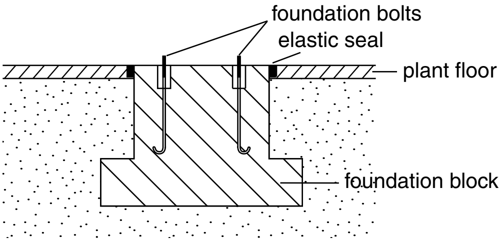

FIGURE 3.4 Typical press foundation.

If the bottom of the press base is below floor level (in a pit), then sufficient gap should be provided around the press for maintenance, repair, and part replacement (Figure 3.5). For safety, this gap is covered with plates or grates.

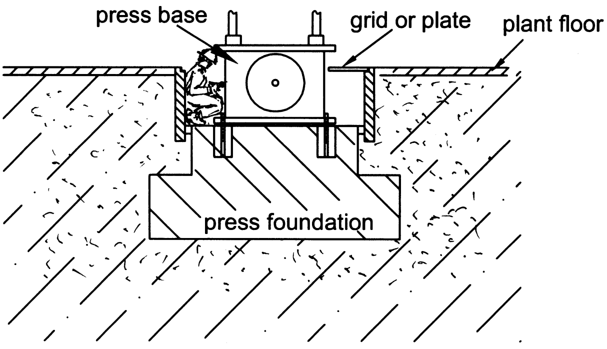

FIGURE 3.5 Presses installed in a pit should have enough space around them for maintenance, repair, or part replacement.

3.2 Mechanical Presses

3.2.1 Four-Post Undercrank Presses

Any type of mechanical press can be incorporated into a roll forming line. Product manufacturers occasionally use OBI, straight-side, or other standard presses available in the plant. In some cases, press brakes are employed to prepunch long patterns. However, these types of presses are usually expensive and frequently too slow for the line.

The roll forming industry has developed their own less expensive presses which are better suited for the application. Most of these mechanical presses are four-pillar, intermittently fired, undercrank presses. A typical four-pillar undercrank presses are shown in Figure 3.6a,b. A motor drives a fly wheel, which through a clutch rotates the crankshaft fitted into the base. Through two connecting rods, the crankshaft moves the two cross-heads attached to the posts up and down.

A brake is used to stop the rotation of the crankshaft at top dead center (TDC), which is the highest location of the ram. The eccentricity of the crankshaft determines the stroke. The clutch/brake system limits the maximum number of strokes per minutes. An average small press (20 to 40 ton) may be capable of operating at 50 to 60 strokes/min, a midsize press (60 to 150 ton) 30 to 40 strokes/min, and a 200 to 300 ton press 25 to 30 strokes/min.

Small capacity presses (5 to 10 ton) have been built with two posts only, but four-post presses are more reliable.

3.2.2 Press Capacity

The required nominal capacity of a press is usually established by calculating the force necessary to shear the product during cutoff or needed for punching. The forces required for embossing, swedging, and other operations are, in most cases, guessed, or occasionally established by testing.

The theoretical force required to shear a part is equal to the total sheared cross-sectional area multiplied by the shear strength of the material:

$$F = L \times t \times S \tag{3.1}$$

where

F = force lb (kN)
L = length of shear in. (mm)
t = thickness in. (mm)
S = shear strength psi (MPa)

For example, to cut off (shear) a 0.040-in. (1.0-mm) thick, 24-in. (610-mm) wide low carbon steel strip, having a shear strength of 50,000 psi (345 Mpa), the required force is

$$F = 24_{(\text{in.})} \times 0.040_{(\text{in.})} \times 50{,}000_{(\text{lb/in.}^2)} = 48{,}000 \text{ lb } (24 \text{ t})$$

or in metric:

$$F = 610_{(\text{mm})} \times 1.0_{(\text{mm})} \times 345_{(\text{MPa})} \div 1000 = 210 \text{ kN}$$

In the case of punching or notching, the total sheared area is multiplied by the shear strength. For example, to punch a 0.5-in. (12.7-mm) diameter hole in a 0.040-in. (1.0-mm) thick low carbon steel requires a force of

$$F = 0.5_{(\text{in.})} \times \pi \times 0.040_{(\text{in.})} \times 50{,}000_{(\text{lb/in.}^2)} = 3140 \text{ lb } (1.57 \text{ t})$$

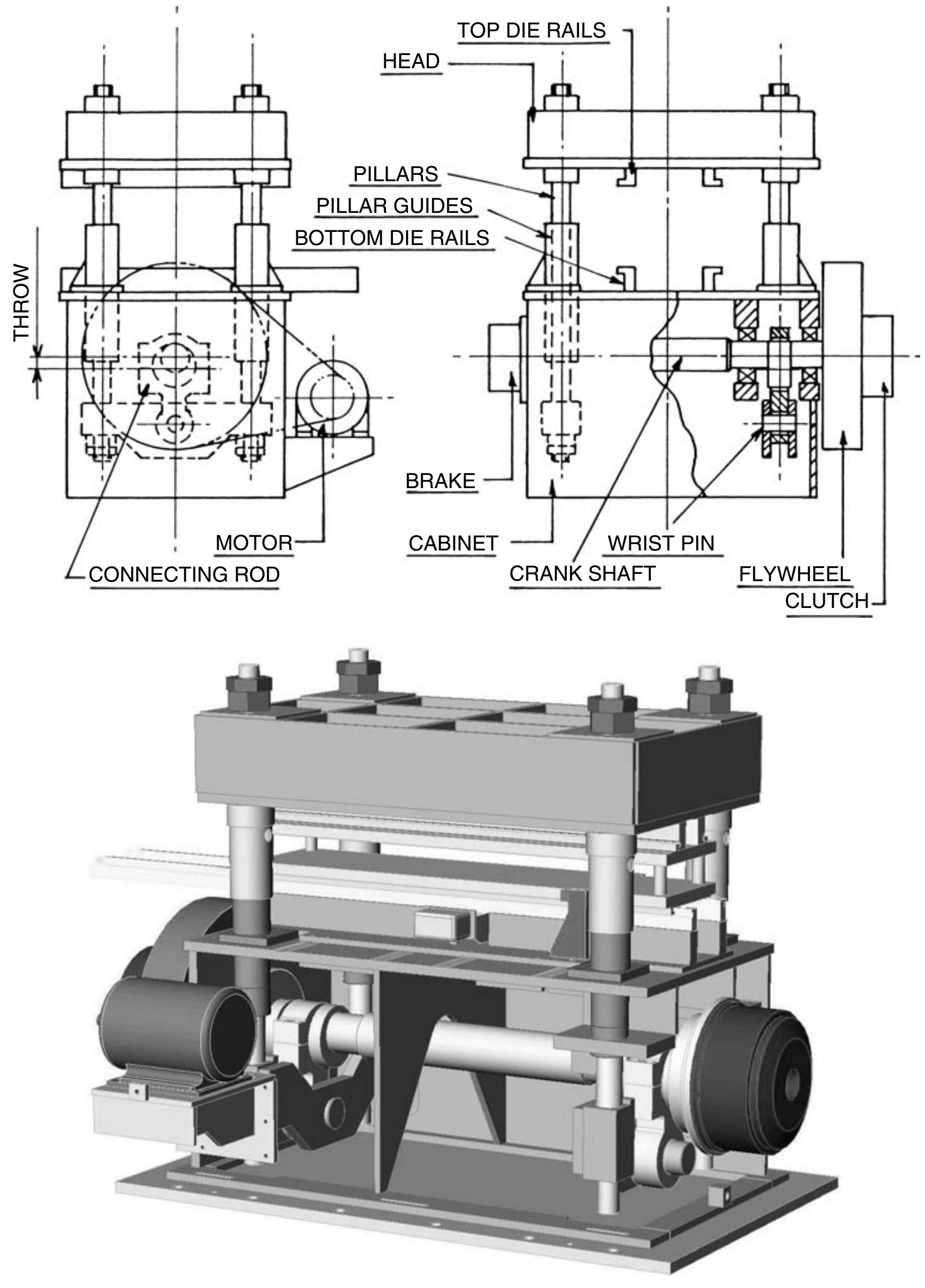

FIGURE 3.6 Typical four-pillar, undercrank, mechanical presses. (Courtesy of Metform International Ltd.)

or in metric:

$$F = 12.7_{(\mathrm{mm})} \times \pi \times 1.0_{(\mathrm{mm})} \times 345_{(\mathrm{MPa})} \div 1000 = 14\ \mathrm{kN}$$

Some factors will increase, while others decrease the total force required for shearing. For example, the pressure required for hold down (blank holder) will increase the total force. Reduced clearance between the punch and die (or shear blades) as well as dull and chipped tooling will increase the force. Brake through during shearing reduces the total force.

The previously mentioned factors, which normally would increase or decrease the total forces, often balance each other. Therefore, a force calculated by the above method can be safely used for preliminary calculation. In budgetary calculations, for low carbon steel, it is sufficient and safe to multiply the total sheared/punched cross-section by 30 ksi to obtain the required force in tons, or in the case of metric calculation, multiplied by 415 MPa to arrive to the capacity in kN.

For example, using the previous data: $24_{(\text{in.})} \times 0.040_{(\text{in.})} \times 30 = 28.8\ \text{t}$ $(610_{\text{mm}} \times 1.0_{\text{mm}} \times 415_{\text{MPa}} \div 1000 = 253\ \text{kN})$ is a safe assumption.

Applying a "rake angle" to the shear blade or to the punches, or staggering the punches will reduce a maximum force. However, the total energy required for the operation will not change because of the increase in the length of travel.

For example, if the shear blade of the above-mentioned example would be of a "bow-tie" type, then having a 2° rake angle (Figure 3.7), then the blade is shearing only 1.14 in. (29 mm) per side at any time. Therefore, the force will only be

$$2 \times 1.14 \times 0.040 \times 50{,}000$$

$$= 4584\ \text{lb instead of } 48{,}000\ \text{lb.}$$

However, the blade travel during engagement, disregarding breakthrough, will increase about 10.5-fold, from 0.040 to 0.42 in. (from 1 to 10.5 mm).

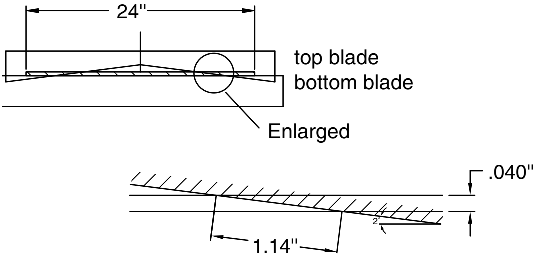

FIGURE 3.7 Rake angle reduces the force but increases blade travel.

Staggered punches have a similar effect. If a punch breakthrough is anticipated at 50% of the metal thickness (Figure 3.8), then following the previous example and assuming that nine punches, each 0.5-in. (12.7-mm) diameter, are staggered in three levels, the required forces will be

$$F = \frac{9}{3} \times 3140\ \text{lb} = 9420\ \text{lb}\left(F = \frac{9}{3} \times 14\ \text{kN} = 42\ \text{kN}\right)$$

and the minimum travel will be

$$3_{(\text{levels})} \times 0.5_{(50\%\ \text{breakthrough})} \times 0.040_{(\text{thickness})} = 0.06\ \text{in.}\ (1.5\ \text{mm}) + \text{safety} \cong 0.1\ \text{in.}\ (2.5\ \text{mm})$$

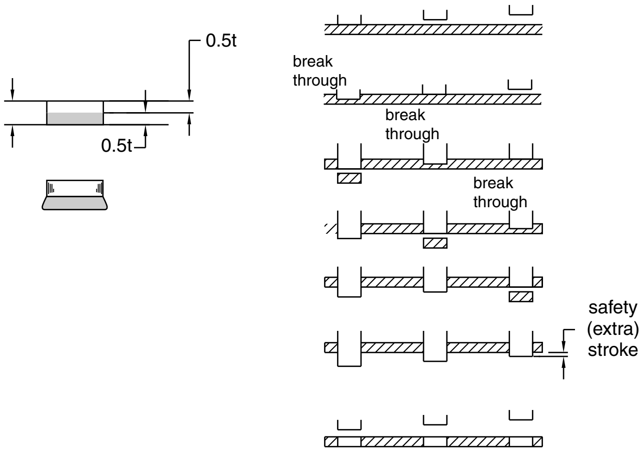

FIGURE 3.8 Punches staggered in three levels.

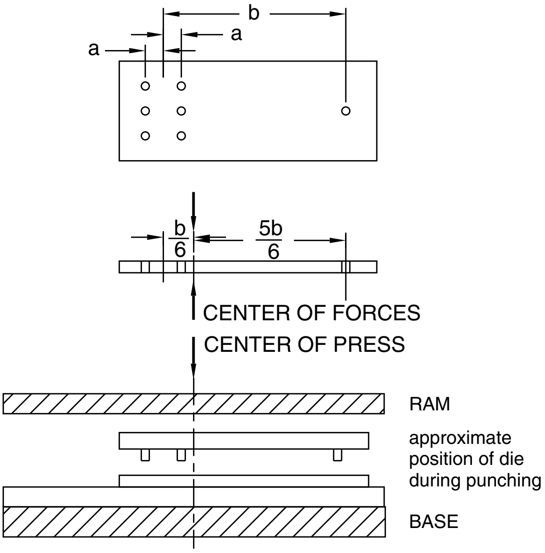

FIGURE 3.9 Forces should be balanced in the press during operation.

As a result, if in the above-described punching operation the punches are staggered in three levels, then the maximum forces on the press structure will be only one third of the total force required. However, the flywheel and the motor must be capable of supplying the full energy required for the operation. In hydraulic presses, the force applied by the cylinder can also be reduced to one third of the force required for nonstaggered punches but the pump capacity remains the same because the travel will be trifold. The unchanged energy requirement can be proven by the previous example: 0.040 in. travel × 48,000 lb. ≅ 0.42 in. travel × 4584 lb.

Staggering of punches or applying rake angle on the punches means longer travel. Too long travel (stroke) after punching through the material can reduce the punch life.

In all press operations, it is important to balance the forces on the die as closely as possible (Figure 3.9).

3.2.3 Force, Energy, Torque, Flywheel, and Motor

The motor and the flywheel provide a reasonably constant torque. However, owing to the eccentricity of the crankshaft, the force extended on the die will be minimum at the midstroke and theoretically infinite at bottom of stroke. Mechanical presses developed for roll forming lines having 3 to 4 in. (75 to 100 mm) stroke are designed to provide their maximum capacity forces at about 0.125 in. (3 mm) above bottom of stroke.

The work expended during the operation (shearing, punching, embossing, etc.) must be replenished by the motor. To avoid sudden increase of load on the motor, the energy required for the operation is provided by the flywheel while it slows down from full speed. The motor replenishes the energy of the flywheel by restoring its speed in time before the next stroke commences.

The kinetic energy stored in a flywheel can be calculated as

$$E = \frac{n^2 \times d^2 \times w}{5.25 \times 10^9} \text{ or in metric : } E = \frac{n^2 \times d^2 \times w}{6.8 \times 10^6} \tag{3.2}$$

where

E = flywheel energy in tons (kJ)
n = revolution per minute of the flywheel

d = mean diameter of the rim (in.) (m)
w = weight of the flywheel rim (lb) (kg)

The above equation [415] is based on an approximately 10% slowdown of the flywheel. Although in the case of single stroke presses, the industry sometimes allows up to 20% slowdown, in flying-die applications, small slowdown is preferred. If the permitted slowdown is 20% instead of 10%, then the kinetic flywheel energy E can be doubled.

Because the flywheel energy changes by the square of the rpm (n), it is advantageous to rotate it fast. However, the stresses generated by the centrifugal forces limit the maximum rim speed. The maximum rim speed of solid cast iron wheel is usually around 6560 ft/min (2000 m/min). The average crankshaft rpm of a midsize press is around 220 to 250 rpm.

A clutch and a brake control the intermittent operation. The clutch usually is an air operated, spring released, friction type, and it can be combined with the air-operated brake.

The flywheel is usually driven by a constant speed, low (3 to 5%) slip AC induction motor.

3.3 Pneumatic Presses

Small pneumatic presses (up to 2.5 to 3.0 tons, or 11 to 13 kN) are frequently made out of C frame type of die holders or similar devices. The force required to punch or shear is provided by an air cylinder, diaphragm air cylinder (Figure 3.10), air spring, or other device operated by compressed air. These small

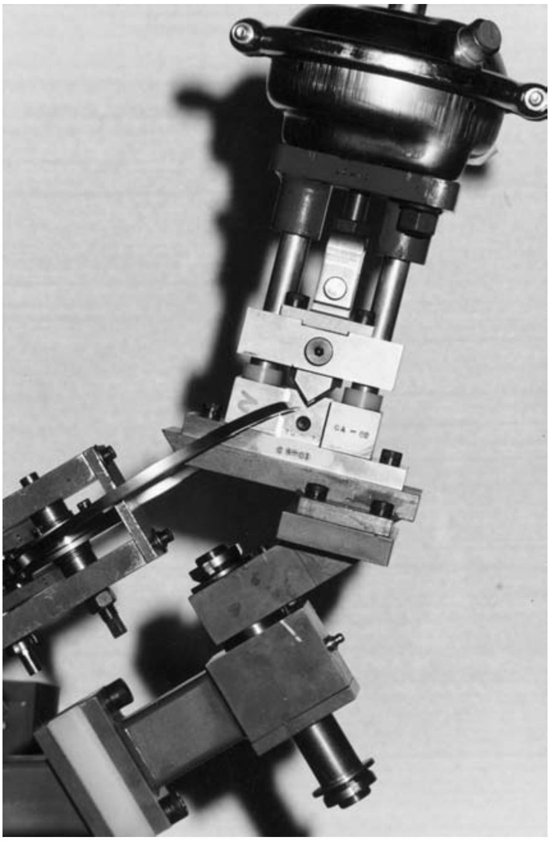

FIGURE 3.10 Small diaphragm cylinder air press cutting curved product. (Courtesy of Delta Engineering, Inc.)

presses are inexpensive and fast. Because of their light weight, they can be used in flying applications. Long patterns are sometimes punched with several such units connected together as a "train."

In almost all instances, shop (plant) air is used. Although the nominal plant air pressure can be 100 psi or more (6.9 bar/0.69 MPa), in press capacity calculations, for practical purposes, a maximum of 70 psi (4.8 bar/0.480 Mpa) is used. The force exerted by these small presses can be calculated as shown below:

$$F = a \times p \tag{3.3}$$

where

F = force in lb (kN)
a = area in in.^{2} (mm^2)
p = air pressure in psi (MPa)

For example, a 4-in. (100-mm) diameter cylinder can provide

$$F = 4^2 \times \pi \div 4 \times 70 = 880 \text{ lb force}$$

or in metric:

$$F = 100^2 \times \pi \div 4 \times 0.48 \div 1000 = 3.8 \text{ kN force}$$

A 10-in. (250-mm) diameter pneumatic cylinder can provide an approx. 5500 lb force (24.5 kN).

Larger air presses, in the range of 5- to 150-ton capacity, are built by companies specialized in air presses. These air presses, consisting of three plates (Figure 3.11), are usually mounted on a fabricated steel base. The die is mounted on the bottom plate, and the center plate (ram) is pushed down by air cylinders or by air hoses. The ram is usually lifted back to its home position by springs.

Large capacity air presses require large diameter cylinders to generate the required force; consequently, their supporting plates must be large. For example, in a 100-ton press, the minimum ram size is about 66 in. (1670 mm) × 46 in. (1170 mm) × 3 in. (75 mm). A large amount of air has to quickly pass through the valves to actuate the press. Most air presses use oversized, special, quick-acting valves. To provide the required amount of air for each stroke, presses have their own

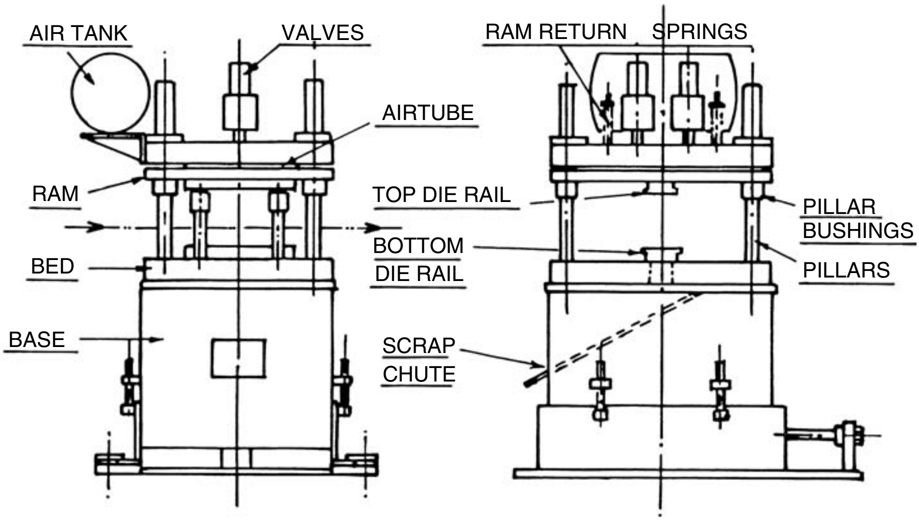

FIGURE 3.11 Typical air press. (Courtesy of Metform International Ltd.)

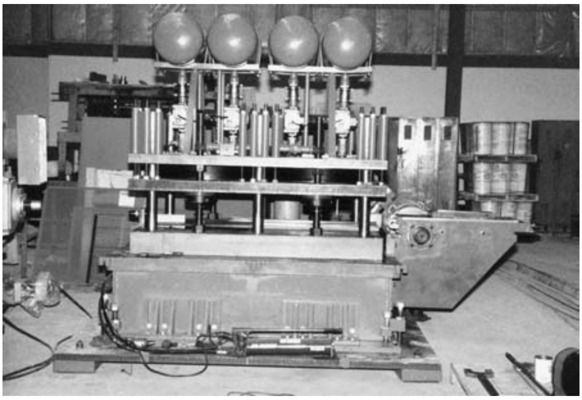

FIGURE 3.12 Large air press. (Courtesy of Contour Roll, Inc.)

tanks. The tanks are usually mounted on the top of the press to be as close to the valves as possible (Figure 3.12).

The press action is very quick. Sometimes, a 0.004- to 0.008-sec opening of the valves is sufficient. Because of its size and thickness, the moving plate (head or ram) is heavy and its inertia greatly contributes to the total capacity of the press. The total press force exerted is a sum of the force generated by the cylinders (or hoses) and the inertia of the heavy plate. The "impact tonnage" rating in the cylinder-operated presses can be about twice as high as the "holding" force created by the air pressure. In the air-hose operated presses, the increase owing to the impact is about 1.5. The inertia can be so significant that in some cases, the valves are even closed before the cutting/shearing action starts. The air pressure, the valve opening time, the force of the lifting springs, and the elastic positive stops establish the lowest position of the ram.

Smaller air presses (5 to 20 tons) can operate over 120 to 150 (or higher) strokes/min. Larger presses are usually slower.

The advantages of the air presses are their lower price, high number of strokes per minute, fast action, and accurate repeatability for use with electronic measuring. The disadvantages are their high noise, big impact and vibration, big bed area at higher capacity range, and large amount of relatively expensive air.

3.4 Hydraulic Presses

In hydraulic presses, one or more cylinders exert the force required for the operation. The cylinder can be located above the ram, pushing it down, or underneath of the base plate pulling the ram (Figure 3.13).

In most cases, the hydraulic fluid pressure is generated by electrical motor driven pumps or occasionally by air cylinders (Figure 3.14).

Smaller C frame press housing is used for punching, notching, or embossing narrow strips or operations close to strip edges (Figure 3.15) In most instances, for regular press work and larger tonnage, four-posted presses are used.

The advantages of the hydraulic presses are their easy adjustability of force, stroke, speed, and accurate repeatability when used with electronic measuring system. The stroke can suit the application and the press generates much less vibration and noise than a mechanical or pneumatic press. Hydraulic

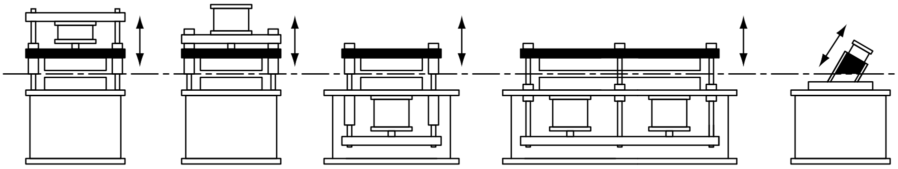

FIGURE 3.13 Different hydraulic press arrangements.

presses cannot be overloaded and because they have fewer moving parts, they usually require less maintenance.

For a long time, speed limitation has been the biggest disadvantage of the hydraulic presses. Hydraulic component manufactures finally overcome the speed restriction by developing new valves permitting the flow of large volume of hydraulic oil in a short time. This development enables the actuation of the hydraulic presses intermittently with almost the same number of strokes per minute as the pneumatic presses.

Shock loads in the system, created by the sudden breakthrough in punching operations, can be critical. Mechanical shock is developed by the sudden change in the compression or tension of the frame members. Hydraulic shock is associated with the sudden decompression of the hydraulic system. The shock load can be reduced by applying rake angle and staggering of punches. In critical cases, internal or external decompression features are built into the hydraulic system.

Off-centric load can create problems by changing the parallelness of the ram and base plate. Linear transducers coupled with servo controlled cylinders can eliminate this problem. Smaller press manufacturers may have to resort to long and rigid guides (gibs) or back gearing to control parallelness.

Calculating the required cylinder diameter is relatively simple.

For example, if 70 t (623 kN) force is required, and the applicable hydraulic pressure is 1800 psi (12.4 MPa), then the minimum cylinder area will be (using Equation 3.3)

$$\frac{D^2\,\pi}{4} = A = \frac{F}{p}$$

In this case

$$\mathrm{A} = \frac{F}{p} = \frac{140{,}000\ \mathrm{lb}}{1800\ \mathrm{lb/sq.\ in.}} = 77.78\ \mathrm{sq.\ in.}$$

or in metric:

$$A = \frac{F}{p} = \frac{623{,}000\ \mathrm{kN}}{12.41\ \mathrm{kPa}} = 50{,}200\ \mathrm{mm}^2$$

where

A = area in in.^{2} (mm^2)
F = force in lb (kN)
p = hydraulic fluid pressure psi (kPa)

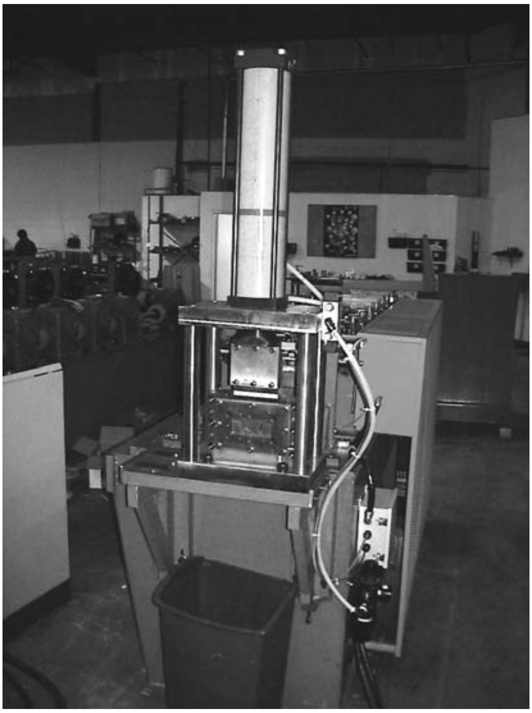

FIGURE 3.14 Air over oil hydraulic press. (Courtesy of CompuRoll, Inc. With permission.)

D = diameter of the piston in inch (mm)

$$D - \sqrt{\frac{77.78 \times 4}{\pi}} = 9.95 \text{ in.} \approx 10 \text{ in.}$$
$$(\approx 250 \text{ mm})$$

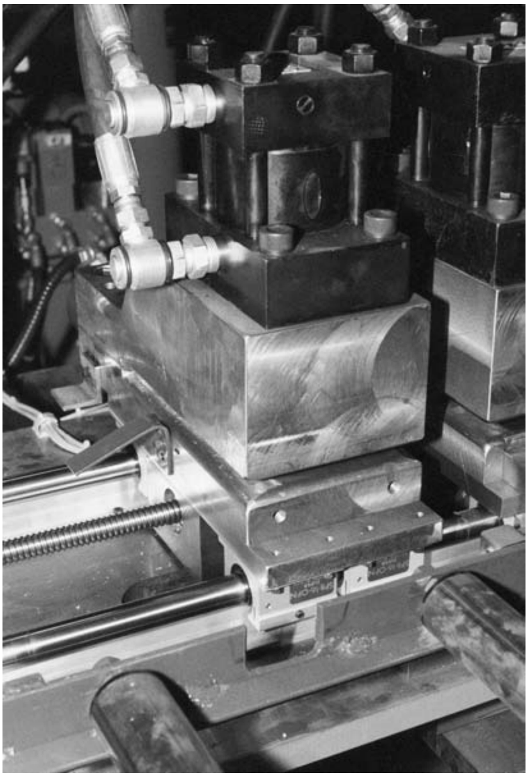

FIGURE 3.15 Small hydraulic "C" notching press (Courtesy of Delta Engineering Inc.)

Note that this simple calculation should be used as a guideline only. It does not take hydraulic losses, time delay, and other components into consideration. For actual applications, refer to the data provided by the hydraulic system suppliers.

If the working stroke is 1 in. (25 mm), then the volume of the 10-in. diameter (250-mm) cylinder in 1-in. stroke will be 1 in. × 78.53 in.^{2} = 0.34 gal, or in metric: 25 mm × 50,200 × mm^2 = 1,255,000 mm^3 or 1.23 l.

When the cylinder returns, the same hydraulic fluid volume minus the volume taken by the cylinder rod will be required. If we assume that the rod diameter is 3 in., then this volume will be 7 in.^{3}. Therefore, $77.78 + 70.78 = 148.5$ in.^{3} (0.643 gal, or approximately 2.4 l) hydraulic fluid is required for one forward and return cycle.

Assuming that the press has to be operated at 50 strokes/min, and that between each stroke, the material (or the flying die) must be moved. Let us assume that the transfer of material takes 0.75 sec. In 50 cycles/min, the material movement requires a total of 50 × 0.75 sec = 37.5 sec. This leaves a total of 22.5 sec for moving the cylinders forward and back 50 times. This equals to 0.45 sec/cycle. During this time, 0.643 gal (2.4 l) hydraulic oil has to be supplied to the cylinder. This requires a pump of $60 \div 0.45 \times 0.643 = 38.6$ gal/min (146 l/min), if the pump is supplying the hydraulic oil directly to the cylinder. During the material (die) transfer period, the cylinder is not moving and the oil supplied by the pump is dumped back into the reservoir.

However, if an accumulator is added to the system, then the hydraulic fluid supplied by the pump is utilized all the time. During the cylinder action, the accumulator supplies a large portion of the oil and the pump recharges the accumulator during the time when cylinders are idle. Following the above examples, it means that the required volume can be supplied in 60 sec instead of 22.5 sec. Therefore, a 14.5 gal (55 l)/min pump will meet the requirements for 1-in. stroke.

For actual applications, the stroke should be reduced to the minimum practical length. For example, punching a 0.060-in. or 1.5-mm thick material, the stroke may be only 0.160-in. or 4-mm long. This means that 0.160 in. ÷ 1 in. = 0.16 times pump capacity:

$$0.16 \times 14.5 \text{ gal} = 2.32 \text{ gal per min } (8.8 \text{ l per min}) \text{ is sufficient.}$$

These calculations are a good approximation but do not take fast approach and slower punching and other factors into consideration.

For practical purposes, the maximum stroke of the cylinder should be around 4 to 6 in. (100 to 150 mm), depending on the die configuration, to make punch and die changes easy. Having a longer cylinder does not change the previous figures because the working stroke will only be the previously mentioned 0.160 in. (4 mm).

3.5 Information and Dimensions for Press/Die Purchasing and Installation

Figure 3.16 (Table 3.1 and Table 3.2) provide the information that press users should obtain from or provide to suppliers when presses/dies are ordered. These data are in addition to the "basic information" required for press installation such as foundation requirements, location and type of foundation bolts, power and air requirements (conduit, wire and air pipe sizes, locations), and others.

Height adjusting, leveling screws, and lateral adjustment should be used at the initial alignment of the press. Once the press is properly aligned and installed, it should not be moved up or down or sideways to suit the dies and product. All rolls, product pass-lines, cutoff and other dies should be made to fit the press accurately. When profiles (dies) are changed, past mistakes should not be corrected by moving the press or adjusting the die shut height, but by reworking the dies. These recommendations are obviously not applicable to special cases such as moving presses to suit curved (swept) parts.

3.6 Rotary and Other Cutting, Punching Equipment

3.6.1 Rotary Devices

Although rotary devices are not called "presses," they can perform many press operations. The advantages of the rotary devices are that they are considerably less expensive than the presses, they can run at any roll forming speed, and can repeatedly produce the same pattern within tight tolerances. The disadvantages are their limitation in handling thick material, and it is very difficult to adjust the patterns although they are repeatedly uniform.

Rotary devices usually consist of two working rolls. It is difficult to synchronize the surface speed of the rotary device with the speed of the roll forming mill. Therefore, in almost all cases, the rolls are rotated by the strip, which is pulled by the roll forming mill. If the rotary device has to be driven because of the high torque requirement, then usually one loop is ahead of the device and one is behind it. The loop controller will adjust the speed of the rotary device or the mill.

To punch, notch, or emboss the lead end of each coil, the pull-through rotary device must be temporarily driven. In small, light gauge applications, the lead end of the strip can be hand-cranked until it is engaged between the rolls in the mill. If larger torque is required, the rolls of the rotary device can be motor-driven at a slow speed. Through an overriding clutch, once the end of the strip is caught by the rolls of the mill and is pulled at a faster speed, the rotary device runs freely.

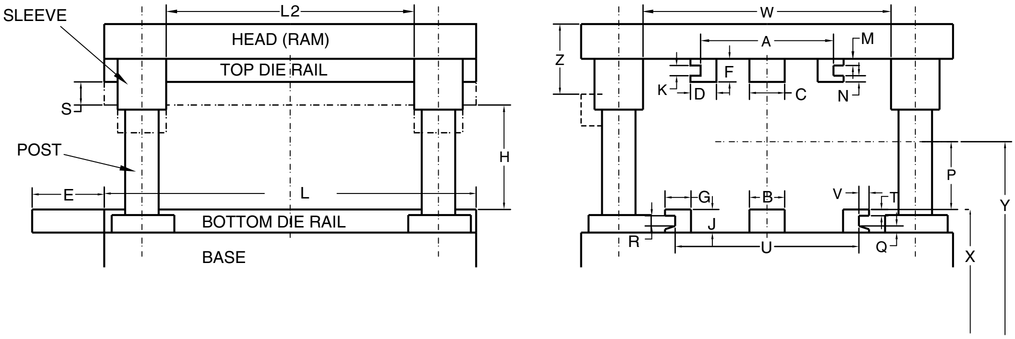

FIGURE 3.16 Press data and information required for die design.

TABLE 3.1 Typical Press Data (see Figure 3.16)

Type	Mechanical ✎ Pneumatic ✎ Hydraulic ✎ Other describe ✎	
Traditional	"C" Frame ✎ Straight side ✎ Link ✎ OBI ✎ Other describe ✎	
Posts	how many 2 ✎ 4 ✎ more specify ✎ .... other describe ✎	
description:		
Press made by		
Model No.		**Year:**
Capacity	Pressure capacity: (work capacity:)	
spm (max.)	number of strokes per minute (intermittent):	

Stroke		**S**	
Shut height (at bottom of the stroke between top and bottom rails or bed.. and head at the highest head position	min typical max	**Hmin** **Htyp** **Hmax**	
Press head adjustability (from highest down)		**Z**	
Die clearance between posts or sleeves F-B		**W**	
Die clearance between posts or sleeves L-R		**L2**	
Rail length		**T**	
Rail extension (if any)		**E**	
Top of the bottom rail above plant floor		**X**	
Pass line height above rail*		**P**	
Pass line height above floor		**Y**	
Press adjustability: height			
Press adjustability: sideways			
Press adjustability: tilting			
Type of die accelerator			
Die accelerator stroke			
Length measuring system			
Other data			

*** (at set press height). Show pass line on section drawing**

Most rotary devices have separate stands, because the punching, notching, or embossing forces are larger than the forces required to form the section in the mill. Furthermore, the stands have to be more precise and they are usually not driven by the drive train of the mill.

Rotary devices are usually mounted at, or close to, the entry side of the mill. With a few exceptions, the male punch and the female die must work together in a precise position. To obtain

TABLE 3.2 Typical Press Information for Die Specifications (see Figure 3.16)

		K		**S**	
B		**L**		**T**	
C		**L2**		**U**	
D		**M**		**V**	
E		**N**		**W**	
F		**P**		**X**	
G		**Q**		**Y**	
H		**R**		**Z**	
J					

Comments:

....

....

....

....

PROVIDE drawings and/or descriptions of:

1. Die rail if different then shown on the drawing (Fig 3. 1) Dimensions within .001" (0.025mm)
2. Line direction
3. Connection to the die accelerator
4. Cams, trigger arms, sensors, switches etc required to operate the press
5. Locations and dimensions of stops, bumpers, shock absorbers etc.
6. Method and details of length sensing
7. Method of die removal (describe it in details)
   In longitudinal direction ✎ across between posts ✎
   Manual ✎
   Fork lift truck ✎ Crane ✎ Other ✎ (describe)
8. Other relevant information:

....

....

....

....

this precise position, sometimes within 0.001 in. (0.025 mm) accuracy, the upper and lower rolls are geared to each other with zero backlash gears. The "mating" position of the two rolls, at least in one position, must be accurately marked to ensure that whenever the two rolls are taken apart for maintenance, rework, or other purposes, they will be assembled back together again exactly in the same position.

The rotary punching and notching processes, the most frequently used rotary operations, are described in Chapter 4.

3.6.2 Cutoff with Rotary Devices

Several methods are used to cut strips or products to length with rotating devices:

- *Scoring*: Short pieces can be cut at high speed to uniform length with rotary scoring. A sharp rotating die mounted in the full length of the roll cuts into the strip at each revolution. The opposite roll can have a flat surface. The distance between the tool and the smooth roll will dictate the reduced metal thickness, which still holds the strip together. This thickness is sufficient to provide continuity to roll forming, but when it is subjected to up and down or sideways bending by deflectors at the end of the mill, the parts break off (Figure 3.17). The disadvantage of this process is that the broken edges can be sharp.
- *Rotary cutting and cold working*: By applying this method, the author had designed and built equipment to cut 2 in. (50 mm) pieces with both ends flattened (Figure 3.18). The line speed was 750 ft/min (230 m/min), producing 4500 pc/min.
- For another application, the author designed and used a rotary "propeller" type of device (Figure 3.19). This device cut two separate strands into 1-in. long pieces, running at 750 ft/min (230 m/min), thus producing about 18,000 pc/min (equivalent to 300 pc/sec or over a million pieces per hour). The speed of forming was reasonably uniform and the rpm of the propeller

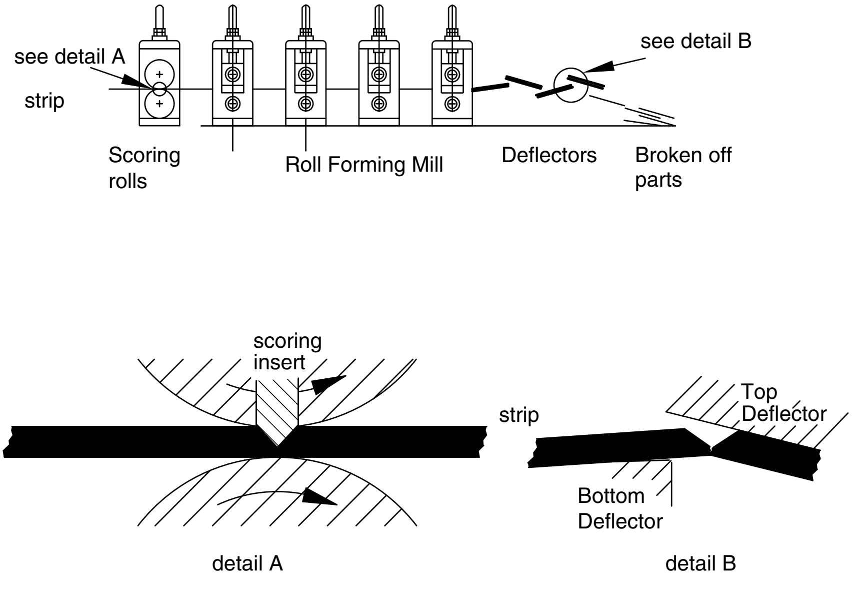

FIGURE 3.17 Shallow products can be scored at the entry end of the mill (A) and broken off at the exit end (B).

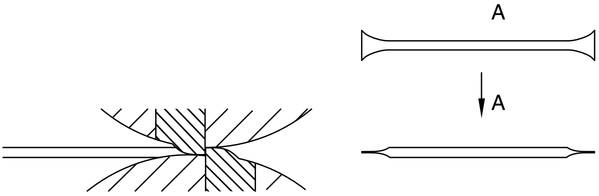

FIGURE 3.18 Rotary cutter cuts and flattens both ends of the product in one operation at a rate of 24,000 pc/min[1].

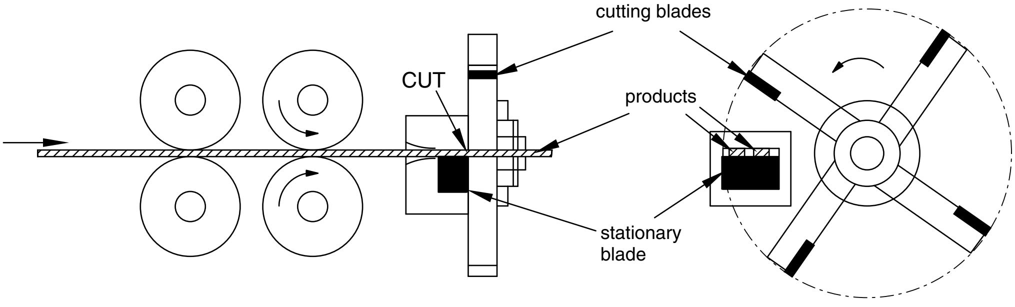

FIGURE 3.19 Rotary propeller type of cutoff equipment.

cutting blades were mechanically governed by the rpm of the forming rolls. This arrangement provided close tolerances on the 1 in. long pieces.

It was relatively easy to apply this process to rigid products, such as high strength, low elongation material having a cross-section of 0.001 in.^{2} (0.65 mm^2).

- *Cutting with arc motion*: Flying cuts can be made with blades moving in an arc motion (Figure 3.20 and Figure 4.103). The rotation of the top and bottom blades is tied together with the zero backlash gears or linkages. The back and forward movement can be accomplished with a die accelerator or with linkages. The center of the top blade holding-arm is in a fixed position, whereas the center of the bottom blade holding-arm can be moved up and down or both centers can be moved up and down.

  Before cutting, the bottom center is in the upper position. When the signal is given for cutting, the two blades swing forward, overlap each other, and cut through the material. When the cut is finished, the center of the bottom blade holding-arm moves down, both blades swing back to the starting position without touching the material, and then the center of the bottom blade holding-arm moves up to the starting home position. One disadvantage of the arc movement is the restricted depth of the cut. Therefore, this system is used only to precut strips. The arc motion can be substituted with a better pattern by using proper linkage systems.
- *Cutting with parallel linkages*: Another system, patented long ago, utilizes parallel-moving plates, acting like connecting rods (Figure 3.21). The two connecting rods shown in the figure represent the die plates to which the cutting dies (blades) are attached. This system eliminates the angular flotation of the blades described in the previous section; thus, it can be used to cut finished products, such as tubes, at high speed. However, owing to the rotary motion, the speed of the die plates in the horizontal direction changes during engagement.

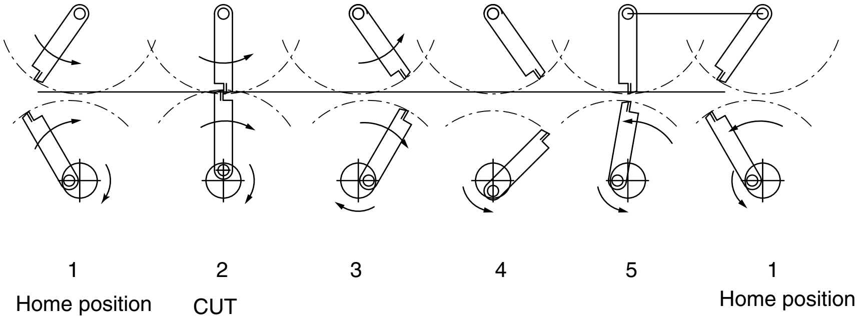

FIGURE 3.20 Arc motion flying shear.

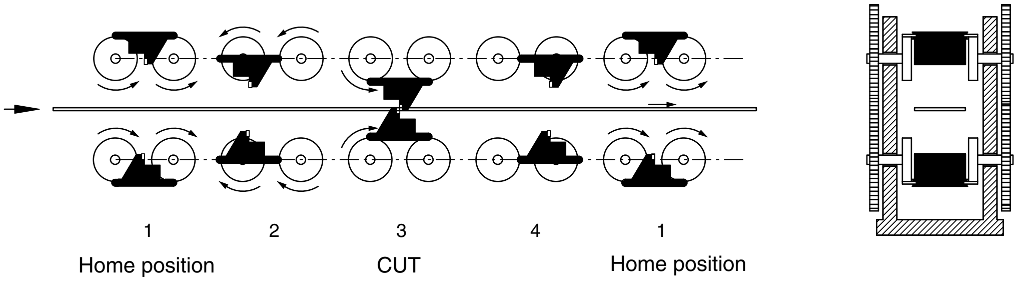

FIGURE 3.21 Schematic representation of a parallel linkage flying shear.

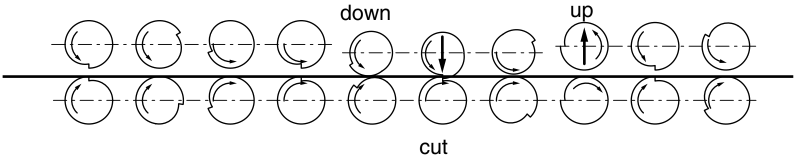

FIGURE 3.22 Rotary cutter combined with up and down movement.

- *Rotary cutoff with up and down movement*: The simple rotary cutter mentioned in the first part of this section cuts all pieces to the same length at every revolution (or cutting two to three or more pieces per revolution if two, three, or more blades are installed in the rotating body).

  The simple principle of this modified system is that after cutting, the two rolls are separated at a distance just slightly more than the material thickness (Figure 3.22). However, the upper and lower rolls remain connected together all the time with zero backlash gears. In the upper position, the rotating blade is not in touch with the material and is not cutting. When a cut is required, a signal moves the top roll down, and the blades overlap each other at one point during rotation. The length of the cut piece can be adjusted by slightly reducing or increasing the rpm of the two rolls while they are not in contact with the material. Just before cutting, the rpm of the rolls is changed to meet with the speed of the strip. The top roll moves down, completes the shearing, and then moves up again. Proper programming allows changing the cut lengths without stopping the process.

3.6.3 Flame, Plasma Jet, Laser, or Other Cutting Methods

Cutting the product by melting is rarely used because of the slow cutting speeds. If this method is applied, it requires good speed matches. Nonmatching or fluctuating speed will result in bad cuts or incorrect cutting pattern.

3.7 Flying Die Accelerators

3.7.1 Pneumatic Die Accelerators

Accelerating a flying die from its standing (home) position to the speed of the strip by a pneumatic cylinder is a relatively inexpensive method (Figure 3.23). However, the accuracy of the pneumatic die accelerators is relatively loose.

In most cases, a length or a whole location-sensing device provides the signal for the operation. The signal activates a solenoid valve that supplies air to the die accelerator cylinder. The cylinder accelerates the die, which slides on the die rails. When the die starts to move, it actuates the press.

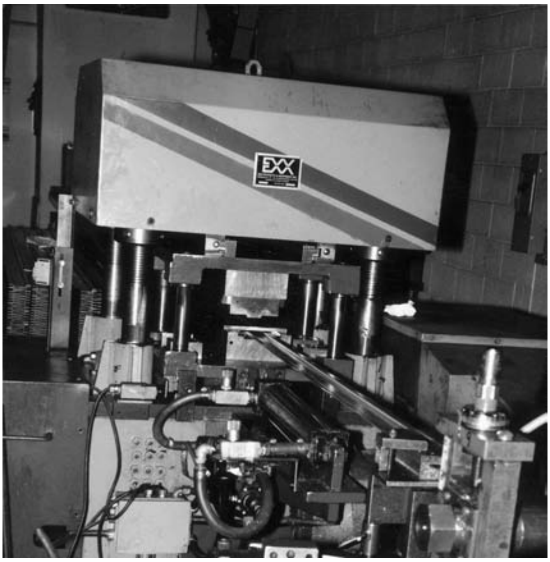

FIGURE 3.23 Air cylinder die accelerator.

For optimum performance, the flying die should travel at the speed of the strip when the tool engages the material, at about the center of the press. Once the tool is engaged, the die will travel with the speed of the product (strip) until the operation is completed and the tool (cutoff blade) is disengaged. After that point, the cylinder will decelerate the flying die and, after a momentary stop, will return it to the home position.

In reality, the die acceleration is not linear and it will not be zero (constant speed) when the die speed reaches the speed of the strip. Moreover, the speed of the die is also influenced by the changing friction between the die rails and the slides, and by the fluctuation in the pressure and volume of the compressed air. Furthermore, the speed of the flying die is not measured accurately. In most cases, it is adjusted by eye to match the speed of the strip. These factors, superimposed on other factors such as fluctuating strip speed, press stroke speed, accuracy of the length (position) of measuring device, and others, reduce the tolerance.

The actual tolerances can vary greatly, but in most cases, ±0.25 in. (±6 mm) can be achieved for products running at about 120 to 180 ft/min (36 to 55 m/min).

The area of the die accelerator air cylinder is determined by dividing the calculated die accelerating force by the available air pressure:

$$\frac{F}{p} = A = \frac{D^2\,\pi}{4}, \qquad \text{hence} \qquad D^2 = \frac{4F}{\pi_p} \qquad \text{and} \qquad D \cong 1.13\sqrt{\frac{F}{p}} \tag{3.4}$$

Example

Let us say that the required force to accelerate the die is 800 lb (3560 N), and the available air pressure is 75 psi (5.17 bar = 0.517 MPa).

The required cylinder diameter will be

$$D = 1.13\sqrt{\frac{F}{p}} = 3.69\ \text{in., so select a 4-in. diameter cylinder.}$$

In metric, the same result will be 93.7 mm, so select a 100-mm diameter pneumatic cylinder.

At most facilities, air tanks are installed at the press to assure adequate supply of air to the cylinder. To improve accuracy, large diameter hoses/pipes and valves are used from those tanks into valves and cylinders. Sharp 90° turns (elbows) are avoided. To adjust the forward and the return die speeds, the flow control valves are mounted at the cylinder exhaust ports as shown in Figure 3.23.

The cylinders normally push the die to utilize the maximum cylinder capacity (without the rod area). Some manufacturers occasionally install cylinders to pull the dies directly or through chains, cables, or other devices.

Cushioned end cylinders are preferred to avoid impact at sudden stop at both ends of the stroke. To further reduce the impact at the home position, urethane (rubber) blocks, or occasionally shock absorbers are applied.

Air cylinders are also used to engage stops, pick-up pins, engage/disengage (gag) punches, and for other functions to assist die acceleration.

Return only air cylinders are applied to dies, which have been accelerated forward by positive stops, pick-up pins, or by other unidirectional devices.

3.7.2 Air over Oil

To minimize the change in acceleration and fluctuation in die speed, hydraulic speed-governing systems are occasionally used. In these cases, the power is still supplied by an air cylinder but a hydraulic flow-control system makes the die travel more uniform. Air over oil types of accelerators provide better tolerances than the pneumatic cylinders. Accuracy depends on the system supplied by different manufacturers. Change in the viscosity of the hydraulic fluid and other factors can also influence the achievable accuracy.

3.7.3 Rack and Pinion

A pinion-gear operated rack, attached to the die, can serve as a die accelerator (Figure 3.24). To minimize or eliminate backlash, either the rack or the pinion gear can be split. The size of the rack, pinion, and the required torque is calculated from the power required to accelerate the die within given time and distance.

The pinion gear is usually driven by a DC motor or occasionally by the mill.

In the case of the older style mill-driven rack and pinion system, the mill drive shaft going to the last forming stand is extended. From this stub shaft, a power transmission (belt or gears), an adjustable speed reducer and a clutch rotate the pinion, which will move the die forward. The speed reducer is used to adjust the speed of the die accelerator to match the speed of the product. When the mill (and the

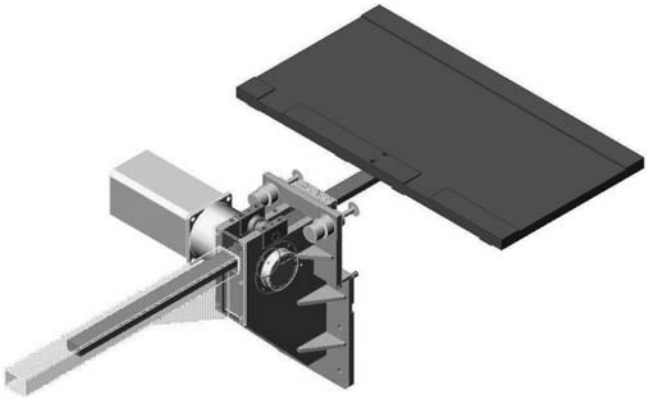

FIGURE 3.24 Rack and pinion die accelerator. (Courtesy of Metform International Ltd.)

product) speed is changed, the speed of the die accelerator is also changed automatically. However, the speed of the product depends not only on the shaft rpm, but also on the pitch diameters of the rolls and other factors. The operators should, but in most cases do not adjust the speed selector to match the speed when the roll sets are changed.

In the case of mill-driven rack and pinion die accelerators, the pinion is rotated in one direction only. The clutch is disengaged when the operation is completed and the die is stopped and returned to the home position by an air cylinder.

The most versatile die accelerator is the DC motor. Very good accuracy can be achieved by using a closed-loop system. In this case, one encoder measures the speed of the strip and its location, and the other one measures the location of the tool in the flying die. When the first encoder gives a signal, the die accelerates, overtakes the strip, and slows down to match the speed of the strip at the right location. When the position is correct, a signal is given to engage the press. During this time, the die is accelerated from zero to full speed within 4 to 8 in. (100 to 200 mm) of travel. The length of the total die travel is influenced by the weight of the die, the speed of the strip, type of the press, and the size of the DC die accelerator motor.

The heavier the die and the higher the speed are, the larger the motor that is required. The increased inertia of the larger motor and drive train can significantly contribute to the torque requirements. However, DC motor-driven rack and pinion drives are known to accelerate a 16,000 lb (71 kN) die to 60 ft/min (18 m/min) at every 6 sec.

3.7.4 Ball Screw

Instead of rack and pinion, a ball screw can accelerate the die. Because of its simplicity, it is often used to accelerate and return small dies. The screw can be located under the die (Figure 3.25). In the case of larger dies and higher speeds with long travels, the buckling strength of the screw can be the restricting factor.

3.7.5 Cam

Cam types of die accelerators are simple, inexpensive, and can provide surprisingly good accuracy. It is usually applicable to smaller dies only.

In this type of accelerator, a cam is fastened to the die and a cam roller or other device is mounted on the ram. When the sensing device gives a signal, the ram moves down, the roller hits the cam, which kicks the die forward (Figure 3.26). After the ram starts to move up and the tool disengages from the material, the springs or other device will pull the die back to its home position.

If the vertically traveling roller attached to the ram hits a straight cam, then in principle, it will start to move the die instantly in the horizontal direction. The impact can be reduced and the die speed better controlled by changing the cam for gradual acceleration (Figure 3.27). A well-designed cam accelerator can achieve ± 0.030 in. (0.75 mm) tolerance at medium speeds.

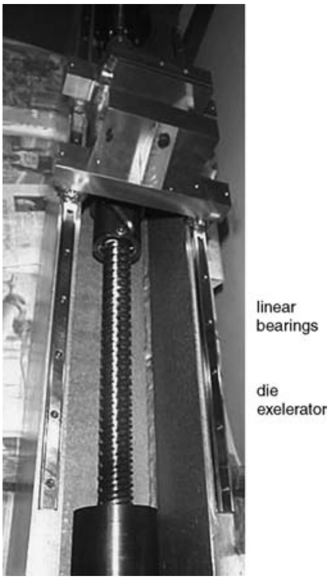

FIGURE 3.25 Ball screw die accelerator.

3.7.6 Strip/Product

Flying dies are often accelerated and moved by the product. The die can be moved by the tool

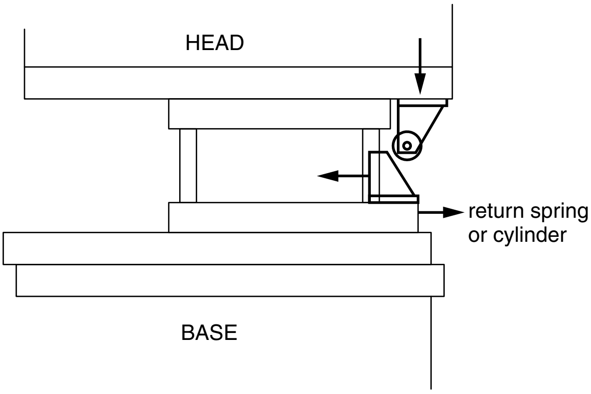

FIGURE 3.26 Schematic representation of the cam-type die accelerator.

engaged into the material, by friction, by inserting a pin or stop into a prepunched or notched hole, or be pulled by the previously cut end. Sometimes, a combination of the above methods is used:

- A sturdy punch entering into the moving strip can accelerate the die from zero to full speed without damaging the tool or the strip.
- Positive stop is a very frequently used die accelerating method. After each cut, the end of the product exits from the cutoff die and travels at the forming speed towards a stop. This stop is rigidly attached to the cutoff die by a rod (Figure 3.28). When the end of the product hits the stop, it moves the stop forward with the die attached to it. The moving die triggers the press. After cutting, the stop is moved or rotated away from the product. The product slips out and the stop with the die is returned to the home position.

  There are about as many different designs as many positive stops. All have a rigid stop, a sturdy arm, a mechanically, pneumatically, or electrically actuated release mechanism, and an adjustable connection to the die.

In all cases, the strip or finished products must overcome the inertia and the friction to accelerate the die from zero to the strip speed. Different methods must be used to overcome problems if the engaged

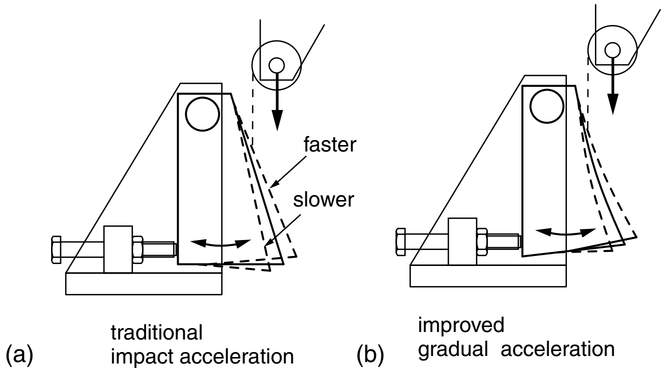

FIGURE 3.27 Improved cam design reduces impact and accelerating forces.

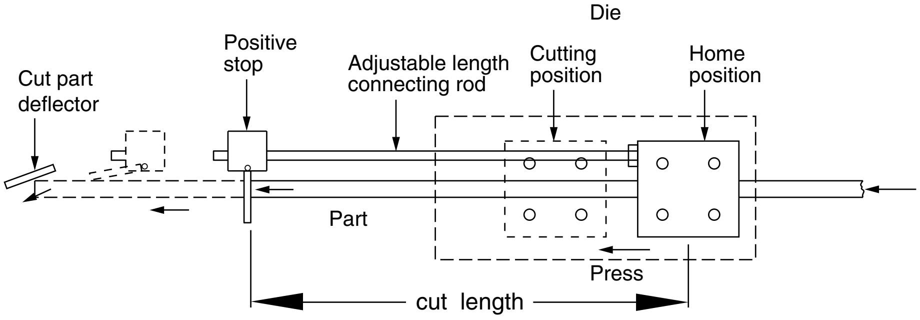

FIGURE 3.28 Positive stop die accelerator.

punching tool is too weak, or the pin entering into the prenotched hole is too small, the strip is too thin, the die weight is too high, or the roll forming speed is too high.

In some cases, a pneumatically operated “grab pad” can be attached to the die. When the grab is pressed against the strip, then it starts to move the die, even before the punch enters into the strip. The grab can be disengaged just before or at the time of removing the punches from the strip.

Because the distance between the stop and the die is fixed, these methods provide good tolerances at a relatively low price.

Another way to overcome the die accelerating problems is to use a differential valve. The valve applies just enough pressure to the forwarding side of the die return cylinder to compensate for the friction. This pressure almost moves the die forward and makes it easier for the product to move the die when it hits the stop. A larger pressure can be used to the return side of the cylinder to move the die quickly back to the home position.

Another possibility is to use the die return cylinder or other short stroke cylinders to kick-out and start to move the die just before the product hits the stop. The impact between the product and the already moving die will be much less than hitting the stop of a standing die. In some cases, by using this kick-out method, it is possible to increase the roll forming speed restricted by buckling by 100 to 200%.

3.7.7 Pick-Up

This method is similar to the positive stop, but the die is pulled by a pin or other device entering into a prepunched hole or prenotched opening. In these cases, the product length tolerance is established by the accuracy of prepunching.

Pick up is a frequently used method when prenotching is required for postcutting. The previously mentioned restrictions (speed, die weight, pick-up pin, size, etc.) also apply to this method. To overcome these restrictions, a kick-out springs or a pneumatic cylinder die accelerator can be used.

3.7.8 Miscellaneous Applications of Die Accelerators

Die accelerators are also required for other cutting methods such as cutting the product with saws or heat.

Saw and friction-saw cutting require a good speed match between the product and the saw carriage to avoid blade breakage. Frequently, this can be achieved by using grabs or other pneumatically operated clamps attached to the flying carriage. Small, complex, miter-cut aluminum sections, and foam-insulated panels are frequently cut with saws.

It is more complicated to obtain synchronized speed with the saw when the product is not only traveling forward, but also rotating. This helical motion happens when corrugated spiral culvert and other pipes are roll formed (Figure 4.106).

3.7.9 Die Return Springs

Dies moved forward by the strip, finished product, cam or other methods are frequently returned to their home positions by springs. Choosing the springs is critical. They should have the sufficient strength to return the die quickly without exerting too much force against the accelerating device, and have just enough force at the home position to ensure that the die does not bounce away from the home position stops. Therefore, the die return springs are usually long.

Very rarely, rubber bands are used to pull back the dies.

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4.1 Secondary Operations

Some products can be applied “as roll formed,” but a significant percentage requires additional operations such as punching, notching, curving, welding, or others. If these operations are made separately, then the product will have to be handled many times; it may have to be moved to the storage from time to time, stored, retrieved from storage, loaded into the machine performing the next operation, then removed again, and finally packed. Completing the secondary operations in this way is time consuming; it requires additional space, and involves a considerable amount of material handling, loading, and unloading. It is therefore labor-intensive and the cost of the in-process inventory will be high. The highly productive roll forming line is a natural place to incorporate the secondary operations whenever technologies permit and quantity justifies it.

Listed below are the typical secondary operations frequently incorporated in the roll forming lines:

- Punching
- Perforating
- Flanging
- Notching
- Lancing
- Stitching
- Louvering
- Hole flanging
- Piercing
- Partial punching
- Mitering
- Slitting
- Expanding
- Cutting
  - before roll forming
  - in-between roll forming
  - after roll forming
- Embossing
- Bending
- Straightening, Curving (Sweeping)
- Marking
- Coining
  - Serrating
  - Knurling

- Swedging
- Mechanical joining of different strips or materials
- Soldering, brazing
- Arc or other types of welding
- Resistance welding
- Adhesive bonding
- Painting
- Caulking
- Foaming
- Packaging

4.2 Straightening

4.2.1 Need for Straightening

One basic rule of the roll forming process is to bend the starting flat strip in a straight line, in the longitudinal direction. However, the stresses created by the forming, compounded with the residual stresses in the starting material, frequently force the product to deviate from a straight line. The most frequently used terms to describe the deviations after they exit from the last pass (see Figure 4.1) are:

- Camber — in the horizontal direction
- Bow — in the vertical direction
- Twist — shaped in a spiral form

To correct these problems, straighteners are used at the exit end of most roll forming mills.

These straighteners, which correct the deviation from straightness of the roll formed products, should not be confused with the flatteners. Flatteners are used, when needed, to flatten the strip ahead of the roll former.

Wide building panel sections with many straight bend lines usually do not require straightener.

The residual stresses in the end-products are also creating deviations from flatness, such as edge waviness, center waviness, ripples, and herringbone effects (Figure 10.38h–ℓ). However, straighteners cannot remove these deviations from flatness from the product.

4.2.2 Basic Rules of Straightening

The straightener is forming the product with a camber (curved in the horizontal direction) or with a bow (curved in the vertical direction) with enough pressure to create a permanent deformation in the opposite direction of the deviation. If the deformation in the opposite direction is correct, then after springback, the product will be straight (Figure 4.2).

If the product has a twist in one direction, then the straightener must rotate it in the opposite direction beyond the yield limit to create a permanent deformation. If the angle of the correcting rotation is right, then after springback the product will exit straight without twist.

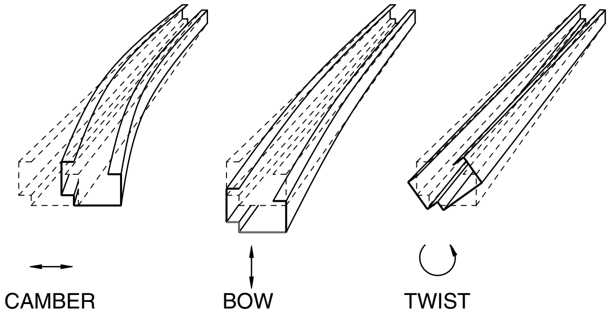


FIGURE 4.1 Deviations from straightness.

Bending or twisting is usually corrected between the last pass roll and the cutoff die. If the last pass is not supporting the product sufficiently, then the full cross-section has to be supported at the entry side of the straightener.

When an asymmetrical section is straightened, the straightening may induce twist. In this case, a combination of bending and twisting in the opposite directions is required.

The straightening of the product does not require an all-around contact between the straightener and the product surface. However, it is important that the straightener should be in contact with the product at and around the bend lines (Figure 4.3). To avoid deforming the product, the radius on the straightener should match the bending radius of the product.

During straightening, the product is either pushed up or down, or either left or right. Therefore, straighteners can fit rather loosely on the product. A gap between the straightener and the top and bottom, left and right surfaces can be 0.010 to 0.050 in (0.25 to 1.25 mm). If correction of twisting is anticipated, then the gap can be reduced.

4.2.3 Straightening Rolls

Rolls are the simplest and longest-lasting straightening tools. They can be best applied if they can reach into the bend lines (corners). A typical application is shown in Figure 4.4.

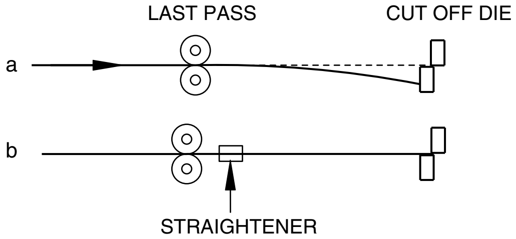


FIGURE 4.2 Straightener forces the product opposite to its deformation.

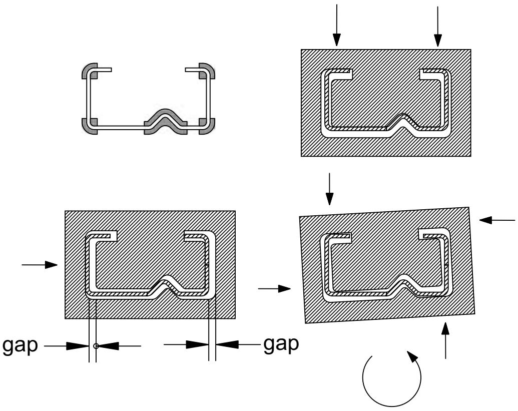


FIGURE 4.3 Straightener block should be in contact with the strongest parts of the product (bend lines).

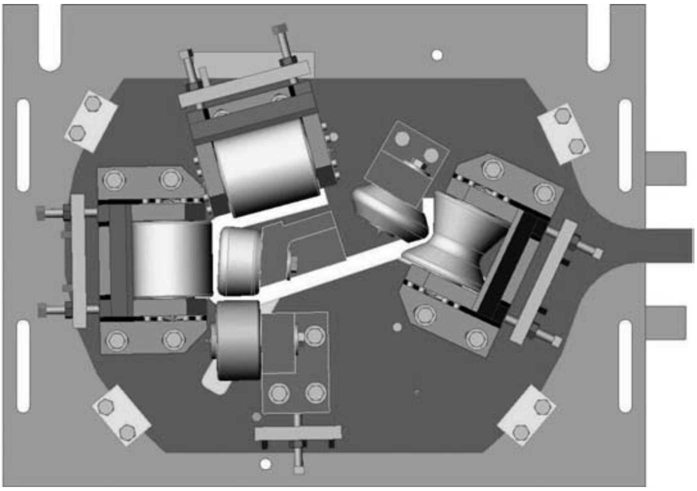


FIGURE 4.4 Heavy section straightener with rolls. (Courtesy of Metform International Ltd.)

Straightening rolls (called "Turks heads") enveloping a product are also used by the tube industry as shown in Figure 4.5.

Tool material for the straightening rolls is usually the same as used for the forming rolls. Straightening rolls are usually not driven.

4.2.4 Straightening Blocks

Blocks are the most frequently used straightening tools. The blocks envelop the section and can reach into the bend lines (Figure 4.6).

Straightening blocks are usually made from two or more segments to facilitate machining adjustment, replacement of worn parts, and dismantling if required. A large entry opening (fish-mouth) is necessary to guide the leading end of the product gently into the block (Figure 4.7) and to provide a smooth travel of the product into the straightener even at extreme positions (Figure 4.8). A similar but usually smaller fish-mouth is required at the exit end of the block. In most cases, an approximately 2-in. (50-mm) long block is sufficient for most products but the large and thick section may require longer blocks.

AMPCO or equivalent bronze is the most frequently used material for the blocks. AMPCO 18 has a good wear resistance. Higher numbers (e.g., AMPCO 21) have better wear resistance but are more difficult to machine. Lower numbers may also wear too quickly.

Thin material with a nonabrasive surface such as prepainted aluminum, may be straightened with plastic (nylon, teflon, or other) blocks. However, plastic is more vulnerable to scratches by the burr created at punching or notching.

For short test runs, well-lubricated hardwood block can suffice.

The blocks, supported by the straightening unit, must have sufficient strength to force the product up or down, sideways, and/or twist it.

4.2.5 Combination of Straightening Rolls and Blocks

In a few cases, the rolls and blocks are combined to achieve the optimum result. The blocks are added to locations which cannot be reached by the main straightening rolls.

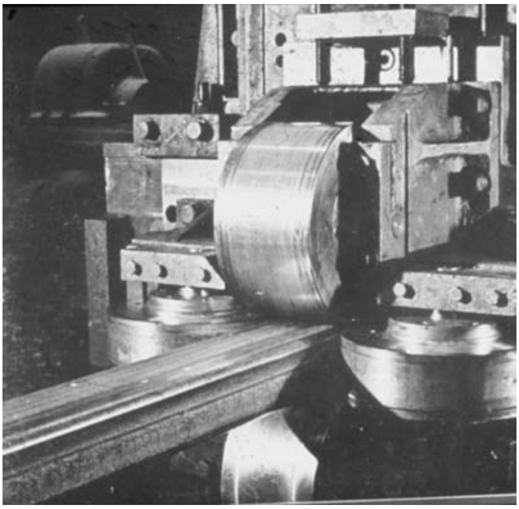


FIGURE 4.5 Turks-head straightener.

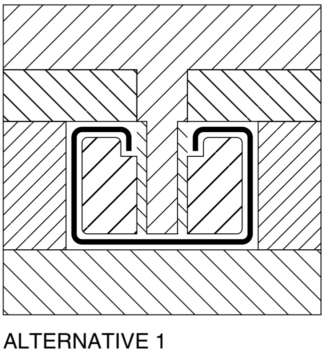


FIGURE 4.6 Straightener block made from several sections.

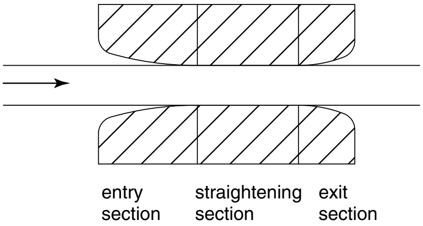


FIGURE 4.7 Straightener block should have large fish-mouth entry side.

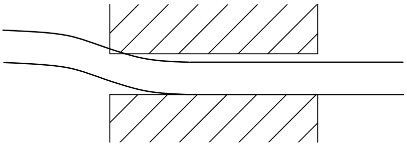
4.2.6 Straightening Units

Straightening units support the straightening tools (rolls and blocks) and provide the tools' movement in the horizontal and vertical directions as well as their rotation. The straightening unit and the tools (usually called the "straightener") are almost exclusively located after and close to the last roll forming pass. The position of the straightener is critical. Installation can be made easier if the base of the straightener is keyed to the base of the mill or other subbase. The key, fastened to the mill bed, will locate the straightener always in the same position.

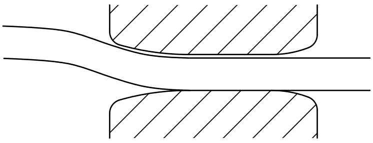
The position of the center of location of the straightener die is critical. The center of rotation should be about at the center of gravity of the product (Figure 4.9).

The straightening unit must be sturdy. The strength is required to bend and twist the product beyond its yield strength. It must also withstand the full longitudinal pushing force created by the mill without being damaged when the product hits it during the feed-in operation or when the product got stuck in the straightener. In these cases, the product should buckle in the short distance between the last pass and the straightener without causing damage to the straightener.

The straightener has to be easily, quickly, and precisely adjustable. A single push–pull screw can move the straightener horizontally. Another single push–pull screw can move the tool holder up and down. The die holder can be rotated by a helical gear type of arrangement (Figure 4.10 Alternative 1) or by another push–pull screw. However, the operator usually can adjust the straightener with better accuracy in either direction when pushing it with one screw against another stop screw (Figure 4.10 Alternative 2).



(a) incorrect straightener block



(b) correct straightener block

FIGURE 4.8 Advantage of the "fish-mouth" straightener entry.

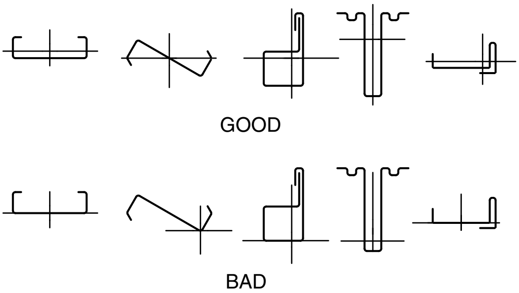


FIGURE 4.9 The location of the centerline of the rotating straightener is critical.

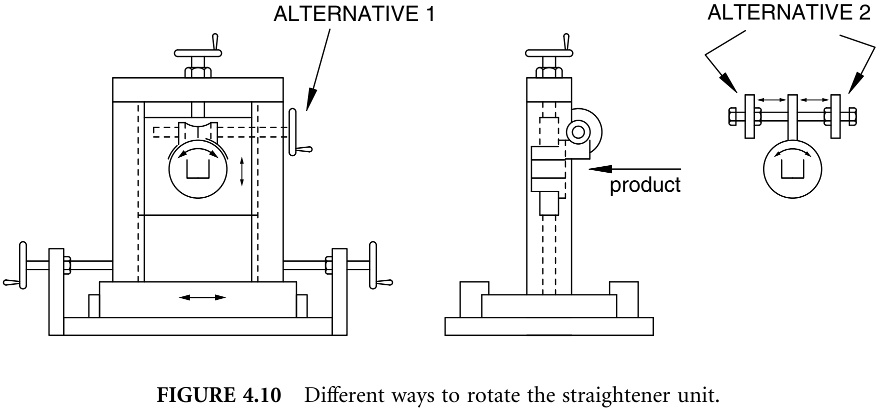


FIGURE 4.10 Different ways to rotate the straightener unit.

When the straightener tools are rolls, then the contacts between the rolls and products are lines. This allows the horizontal or vertical movements in straight lines. However, if the straightener blocks are long blocks, then the straight-line movement will induce additional stresses. Therefore, it is better to move long straightener blocks in a circular motion rotated around a pin or shaft. This orientation will yield less internal stresses and better results (Figure 4.11). Unfortunately, the best straightener arrangement of moving the straightener block in circular motions or in both horizontal and vertical directions is more expensive (Figure 4.12), and therefore it is seldom used.

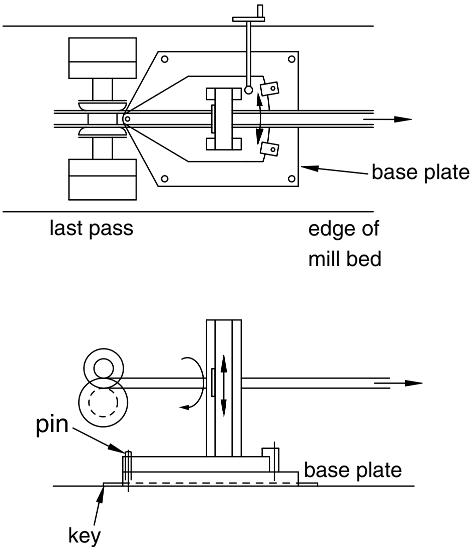


FIGURE 4.11 Adjusting the straightener block in a circular motion is preferred.

4.2.7 Special Straighteners

The industry does not have a "standard straightener." Individual companies may have their own, repeatedly used design for straighteners to suit their requirements.

A few unusual, special, straightening units are listed below.

4.2.7.1 Straightener with Their Own Product Holding Tools

The product is usually straightened between the last pass and the straightener. Therefore, the last pass in the roll forming mill is exposed to similar forces as the straightener. If the last pass rolls are not designed to hold the section rigidly, do not envelop it or if the rolls are thin, then the straightener must have a product holding tool ahead of the straightener (Figure 4.13). A reasonable distance between the straightener and the product-holding tool must be kept because too short of a distance will increase the forces required for straightening.

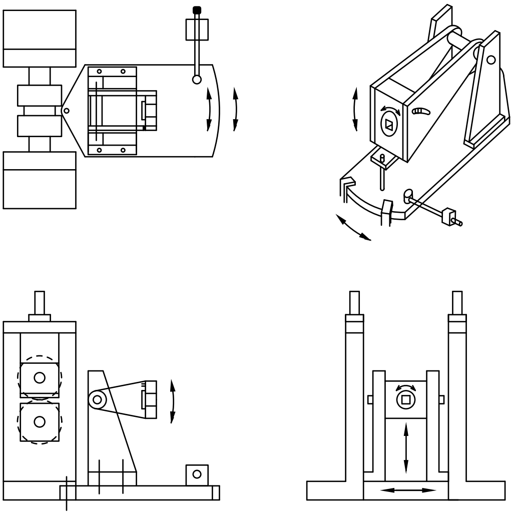


FIGURE 4.12 To provide circular motion in all directions is more complicated.

4.2.7.2 Straightener with Vertical Movement Only

In some instances, the designer can foresee bow in the vertical direction only, without a camber or twist. In this case, a simple straightener with vertical movement only is sufficient (Figure 4.14). Similarly, if the designer foresees a camber only, then a movement in the horizontal direction will suffice.

When wide, flat panels with relatively small edge bends are formed, the panel can easily have a bow or twist. Occasionally, it can happen that one edge is moving up and the other one is moving down. Simple straighteners, moving only up or down at both edges independently, can be used for this type of products (Figure 4.15).

4.2.7.3 Motorized Straightener

The three straightener movements (vertical, horizontal, and rotational) can be motorized. Motorized straightener can be accurately adjusted during operation. They are operator friendly, especially in the case of strong sections. If required, the straightener can be remotely adjusted from a product checking location, positioned after the cutoff die.

4.2.7.4 Automated Straightener

If the bow, camber, and twist are checked with appropriate sensors, the results can be fed back through a PLC or computer to adjust the straightener (Figure 4.16). This automated straightener will yield products with a very narrow tolerance range.

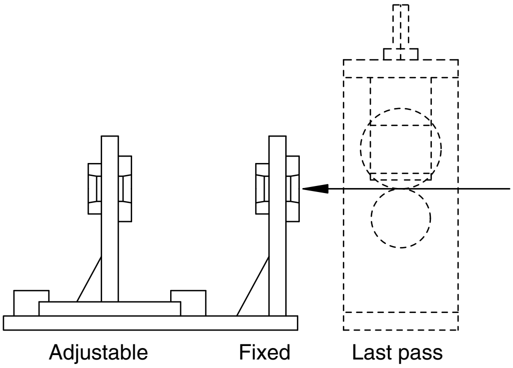


FIGURE 4.13 A fixed unit enveloping the product is positioned ahead of the adjustable straightener.

4.2.7.5 Straightener with the Driven Rolls or Belts

During the straightening process, the product is pushed through the straightening tools by the roll former. The mill operators frequently have problems to pull out the last piece of the coil from the

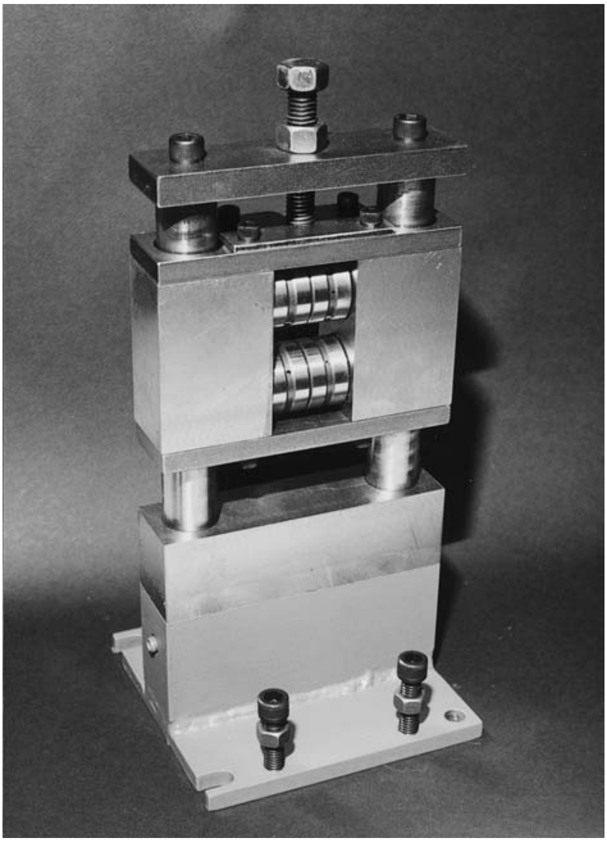


FIGURE 4.14 Roller straightener to correct bow. (Courtesy of Delta Engineering Inc.)

straightener once the product exited from the last pass. For this reason, reprecut pieces cannot be straightened with the usual straightener.

However, there is no reason why the finished product cannot be pulled out from the straightener with driven rolls or belts (Figure 4.17). The surface speed of the rolls or belts can be synchronized with the speed of the product, or other arrangements can be made such as permitting some slippage between the pullout device and the product, or using a slip clutch or utilizing the sensors.

Driven-roll straighteners, especially combined with the previously mentioned holding tools can also be used for many precut products.

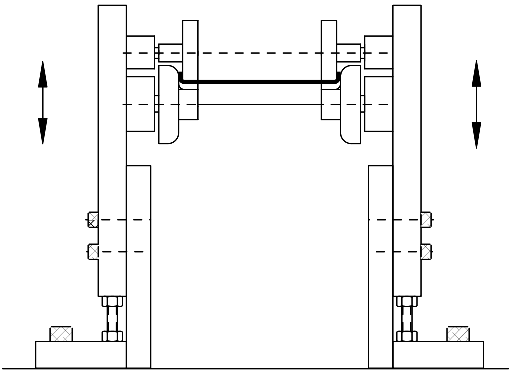


FIGURE 4.15 Straightening the bend-lines at the edges is sufficient in flat panels.

4.2.7.6 Flare Straightener

To remove/reduce flare at the end of the products, special straighteners are used, as described in Section 5.4.4. However, these units are only flare remover/reducers and not through-product straighteners.

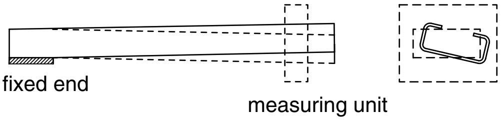


FIGURE 4.16 Deviation from straightness can be measured with sensors.

4.3 Tight or Loose Line: Cutting Before, In-Between, or After Roll Forming

4.3.1 General

Although the strip moves continuously during roll forming, some operations in the line can be completed by the stationary strip (section) method. The location, technology, equipment, and tooling of the secondary operations as well as the resulting quality will be influenced by whether the part is moving or is stationary.

4.3.2 Precutting before Forming

Pieces cut to length before roll forming can run through the mill without stopping. However, some products are stopped for other operations before roll forming, between two roll forming mills, or after

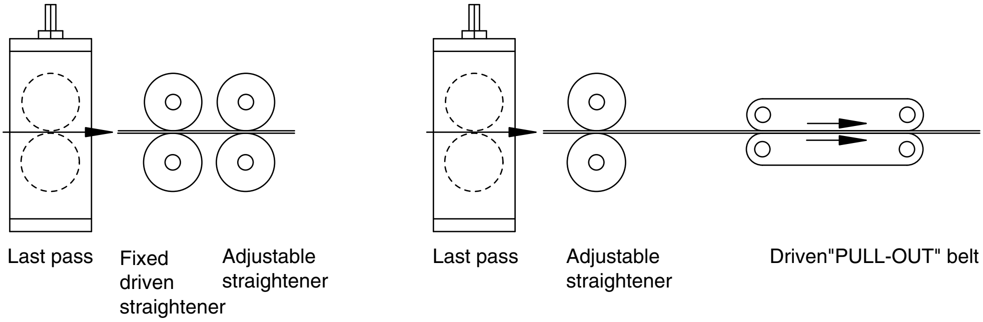


FIGURE 4.17 Driven straightener.

roll forming. Punching, notching, bending, resistance welding, and many other traditional operations can be executed with stationary dies on the stationary strips or products.

4.3.3 Cutting to Length between Roll Forming Passes (or between Two Lines)

Occasionally, the product is partially formed, then cut to length before final forming is accomplished. This technology may be applicable to complex shapes which would either make postcutting difficult, if not impossible, or for other considerations. The cut part can then continuously processed through the remaining part of the roll former at somewhat higher speed.

4.3.4 Secondary Operation in the Line after Postcutting

This is a common approach. After cutting to length, the formed product is either accelerated forward or dropped to a lower level, or moved sideways for the next operation. A typical example is the ceiling tile support "T" rails. They are often roll formed at high speed, cut to length with a relatively loose tolerance, and then moved sideways for progressive trimming to accurate length, punching, notching, and other operations.

4.3.5 Tight Lines

In a tight line (Figure 4.18), every part of the strip is moving until it is cut to length. Therefore, in processes where the tool is engaged in the moving material such as punching, embossing, louvering, and many others, the die must travel (fly) with the material. During this process, the flying die is accelerated from its standing (home) position to match the speed of the material, the operation completed (press down and up), while the die moves at the same speed as the material, then the die is decelerated, stopped, and returned to its home position.

The length sensing system, the die accelerator, the press type, and the speed fluctuation of the strip has the greatest influence on the length tolerances (see Chapter 3 and Table 10.5).

4.3.6 Loose Line ("Free Loop" in and "Free Loop" out)

In a loose line (Figure 4.19), the strip is firstly fed into the press considerably faster than the forming speed of the mill. Then, the strip is stopped, operations are performed, and then the strip is quickly pushed through (or pulled out from) the press. The loop ahead and beyond the press permits quick strip acceleration and high speed. Often, it is easier to accelerate and stop the lightweight strip in one direction than to accelerate and decelerate the hundreds or thousands pounds (kg) flying die in two directions.

In loose lines, the accuracy of the feeder is the most critical factor in length tolerance.

4.3.7 Punching in Loose Line

In the case of loose lines, the complete process (press, tools, feeder, etc.) can be similar to the one used in the press shops. However, the continuous strip is pulled by the roll forming mill with a steady speed. Therefore, in addition to the customary loop ahead of the press, another loop is required after the press, as shown in Figure 4.19.

The loop ahead of the press controls the speed of the device feeding the material into the loop. Usually, this feeding device is a driven uncoiler or a flattener with pinch rolls. To avoid sudden jerky starts and stops, it is advisable to use variable speed drives which only decelerate and accelerate the loop feeding device.

The loop after the press station sometimes governs the press, especially if the mill is slow. At faster speeds, the loop may control the acceleration or deceleration of the roll forming mill.

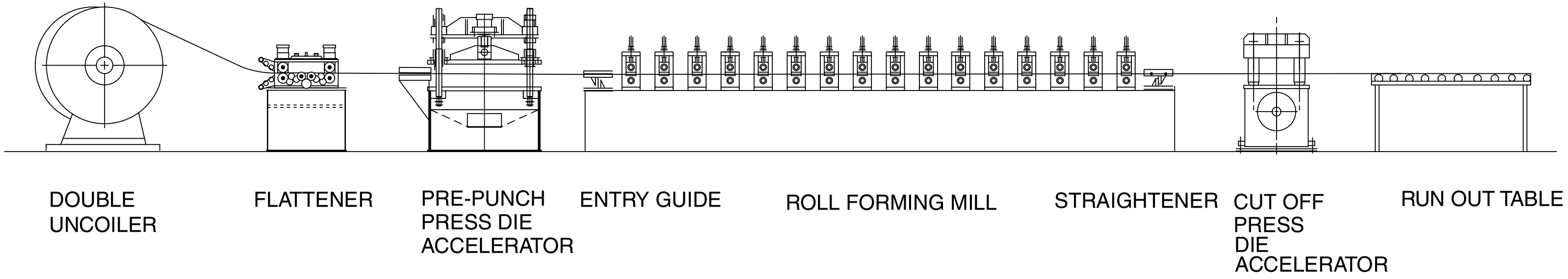


FIGURE 4.18 Tight line with flying prepunching operation.

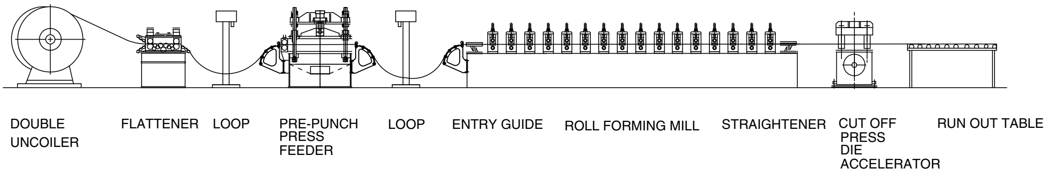


FIGURE 4.19 Loose line with stationary prepunching operation.

4.3.8 Loop before and after the Press

Different types of loops are applied in the roll forming lines.

4.3.8.1 Free Hanging Loop

In many cases, the difference between the length of the loose loop and the tight loop (almost straight line as shown in Figure 4.20) is sufficient to feed the press. Usually, reference literature and suppliers provide equations to calculate the space (length) required for adequate loop (marked as "L" in Figure 4.20).

It is prudent to apply fixed or adjustable "basket rolls" (Figure 4.21) at both ends of the loop to avoid coil breaks.

Although a free hanging chain or rope follows a predictable geometric shape, the stiffness of the strip will change that shape. If punching or notching significantly reduces the strip's cross-section, then the strip's resistance to bending under its own weight can drastically change at that point. These changes should be taken into consideration when the distance between the supports (L) is calculated.

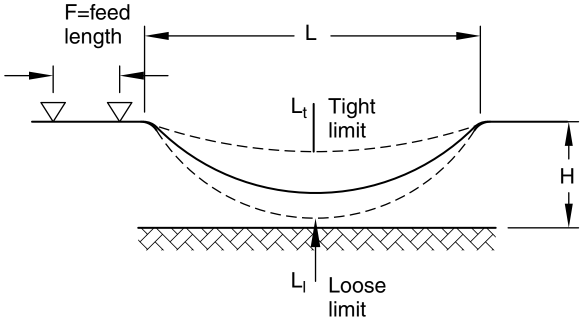


FIGURE 4.20 Loop lengths determine the maximum feed length.

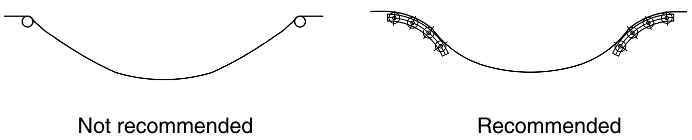


FIGURE 4.21 Basket rolls minimize damage to the coil.

4.3.8.2 Free Hanging Loop with Pit

For long punching patterns (e.g., 3 to 10 ft or 1 to 3 m), frequently there is not enough depth between the supports and the floor to provide sufficient length for the fast feeding. In this case, the designer may recommend using pits (Figure 4.22). Pits can be useful but they are expensive, not safe, and will create additional expenses when the lines are moved.

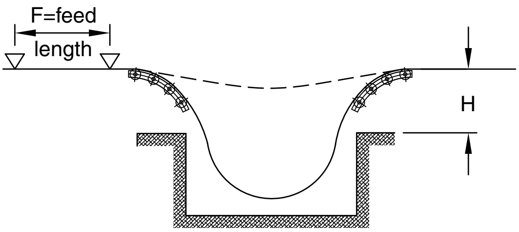


FIGURE 4.22 Loop length increased by using a pit.

4.3.8.3 Folded Free Loop

To avoid making pits in the plant floor, very seldom the excess loop length is allowed to create a free folding loop (Figure 4.23). The loops, in a box-type structure, are supported at the strip edges. The equipment supplier occasionally uses folded free loop during setup tests where the floor does not have a pit. This system is not recommended in production lines, because the strip surface can be damaged and it is difficult to control the loop and the speed of the operation.

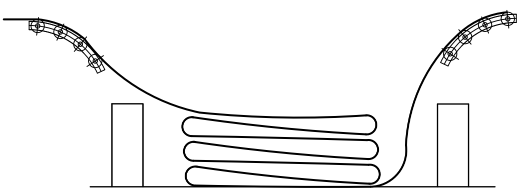


FIGURE 4.23 Folded free loop.

4.3.8.4 Forced Loop

To reduce the space requirement and to avoid the use of pits, the loop can be forced upwards (Figure 4.24). The weight of the strip and the top roll is balanced by counter weights or by cylinders. It can be economically used in front of roll formers but the speed of the ascending and descending top roll can restrict its application in lines with fast accelerating press feeders.

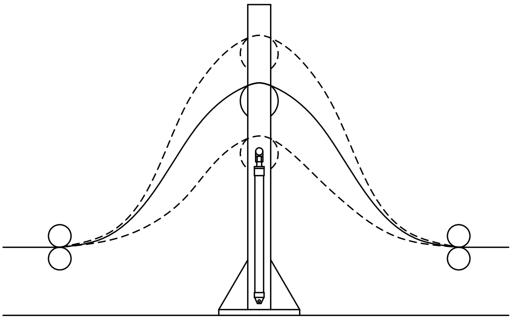


FIGURE 4.24 Forced loop.

It is the tool and equipment designer's function to evaluate all factors, to consider the advantages and disadvantages, and to select the best process. Usually, the production speed, length, and variations of the pattern (e.g., hole pattern created by each stroke), tolerance requirements, method of synchronizing the cutoff, or other operations with the previous operation, the type and thickness of material, the shape of notching or punching, and the price will determine the technology. It is feasible to process one product in tight line and another one in loose line in the same roll forming line.

4.3.9 Stop-and-Go Line

It is extremely rare to stop the line for cutting to length or for other operations. A typical application of this stop-and-go operation is the low speed truck-mounted eaves trough forming. The truck-mounted mill is stopped at the desired product length and the stationary trough is cut with a hand shear.

4.4 Location of the Secondary Operations

The secondary operations can be performed before, in-between, or after the roll forming operation. For a single purpose line or for large production run quantities, it is feasible to choose the most effective sequence of operations. As a result, a single line may consist of one, two, or three uncoilers, one, two, three, or four roll forming mills, several presses or other equipment. The possible combinations are almost limitless. Choosing the right sequence of operations is very important because it will influence the productivity, quality, and manufacturing costs for many years to come.

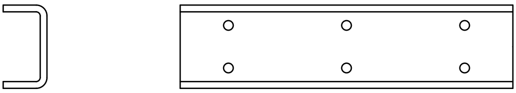


FIGURE 4.25 U channel with six holes.

Even a very simple product such as a "U" channel with six holes (Figure 4.25) can be made in at least 20 different ways as shown in Table 4.1; Some of them are illustrated in Table 9.2 to Table 9.6.

Each method will yield similar looking U channels with six holes, but each one will have different tolerances, productivity, product cost, and equipment/tooling investment.

The selection of the sequence of operations is influenced by the quantity to be produced, frequency of changes, the product cross-section, location of notches, cutouts, their distance from the bend lines and strip edges, dimension and tolerance requirements, as well as the available equipment and funds. Some operations naturally fit into one place only. The more operations are incorporated in the line, the more combinations (permutations) are possible, and therefore the sequence of operation will become more critical.

4.5 Stationary and Flying Dies

4.5.1 Stationary Dies

The punching, notching, mitering, and other operations can be similar to the ones used in the press shops. However, the subsequent roll forming and other processes must be considered at the die design stage. Some of the added factors can be the direction of burr, distance of cutouts from bend lines, how

TABLE 4.1 Different Ways to Make U Channels with Six Holes

First Operation	Second Operation	Third Operation	Variations
Precut strip	Punch one, two, three, or six holes at a time	Roll form	4
Precut strip	Roll form	Punch one, two, three, or six holes at a time	4
Punch strip — punch two or six holes at a time	Roll form afterwards	Cut to length	2
Roll form	Punch two or six holes at a time	Cut to length	2
Roll form	Punch four holes	Cut to length and punch two holes	1
Roll form	Punch two center holes	Cut to length and punch six holes (two at each end)	1
Roll form	Punch six holes and cut to length in the same die one operation		1
Roll form	Cut to length	Punch one, two, three or six holes at a time	4
Rotary punch holes	Roll form	Cut to length	1
		Total:	20

and in what position will the part be cut off, strip continuity (at end mitering), effect of strip camber on hole and notch locations, possible addition of a hole for the cutoff die pick-up pin, and others.

For variable hole, notch, and embossment patterns, gags can control the punches and other tooling. Moving the gags in and out by air cylinder or by other devices, controlled by PLCs or computers, can make changes from hit to hit to create the specified patterns.

In the quick-change lines, where widths or shapes of roll formed profiles are modified in a short time, quick-change tooling should be used. Frequently, only the location of the subdies in a press or the locations of small hydraulic presses are changed. Die or press location changes can be made with servo motors or cylinders, which are often controlled by computers or PLCs.

Dies used in the stationary operations in most cases are similar to the ones used in the press shops. The loops in the loose lines provide similar feed–stop–perform operation cycles. Tools, dies, and feeders are conventional ones, but some additional factors should be considered:

- Orientation of the product (e.g., direction of burr, left-right, etc.). For details, see Chapter 5 (Roll Design).
- Requirement of in the subsequent operations (e.g., added hole for cutoff die pick-up pin).
- Finished products can be very long (e.g., for prepunching, special long presses, or press brakes may be used, but camber in long strip or sheets must be considered).
- Variable length pattern (e.g., variable hole pattern requires programmable rotary feeder or application of several smaller presses with adjustable positions).
- Variable pattern (e.g., combination of gagged punches and programmable rotary feeder or application of several smaller presses with adjustable positions).
- Combination of stationary prepunching and flying postpunching.

4.5.2 Flying Dies

Although the function of a flying die can be identical to a stationary die, its construction is different. Stationary dies are solidly attached to and well supported by both the bottom and top press surfaces (bed and slides). The deflection of these conventional press bed surfaces is limited to about 0.0005 to 0.0010 in./ft (0.042 to 0.083 mm/m).

Flying dies slide on narrow rails. The upper die set is either attached to the press head (ram) rail or only to the bottom die. The die shoe has to be strong enough to bridge over the rails. However, excessive die weight increases the forces required to accelerate and decelerate them.

Therefore, relying on the strength of the die/die shoe combination, the roll forming press designers usually do not adhere to the previously mentioned press bed deflection restrictions.

The flying die set has to be accelerated from the standing position to maximum speed (sometimes up to 400 to 600 ft (120 to 180 m) per minute in a fraction of a second), then decelerated, stopped, accelerated in the opposite direction, decelerated, and stopped at the home position within a total of 1.5 to 0.15 sec.

The die accelerator is usually attached to the bottom die shoe. The inertia created by the weight of the top tool and die plate during acceleration and deceleration generates a “whipping” effect. Therefore, the flying die must have larger, sturdier posts, and guides than the stationary dies.

Brass plates are fastened to the die rails to reduce friction during the die travel. To improve accuracy and to further reduce friction, better dies have spring-loaded rollers running on the hardened steel rails. The springs are lifting the die up 0.010 to 0.020 in. (0.25 to 0.50 mm) above the bottom press rails. When the press head moves down and the punches engage the strip, the pressure suddenly increases. Under the increased pressure, the springs collapse and the brass plates will support the full load. When the head (ram) starts to move up, the springs lift the die, which then moves on rollers again.

In most cases, the top die plate rails are hooked to the press head rails (Figure 4.26).

If an angular or rotary tool movement is required and if the die is small, then the die is attached only to the bottom rails. The press head hits the brass plate fastened to the top of upper die plate, hence the dies are called spanking dies. When the press head moves upwards, the punches are stripped and the upper die is lifted up by springs (Figure 4.27).

Flying self-contained hydraulic press/die combinations are usually traveling on linear bearings (Figure 4.28). These units are self-contained and exert only minimal forces on the rails.

Flying dies are used for punching, notching, flanging, lancing, louvering, piercing, semi-punching, mitering, embossing, bending, marking, coining, swedging, and other operations. The weight of the dies can vary from a few pounds (kg) to 16,000 lbs. (7200 kg). This latter flying die is approximately 48 × 144 in. (1200 × 3660 mm), and is used in a 1000-ton press for products running from 60 to 120 ft/min (18 to 36 m/min) speed.

Flying dies can have gag-operated punches, shears, or other tools to provide variable patterns made by one die.

Most die sets are made for a single cross-section only (Figure 4.29). Some dies can cut a variety of sections without any change (Figure 4.28 and Figure 4.30), yet others can have interchangeable die inserts.

Lines with quick-change mills should have quick-change die features. One quick-change die method is shown in Figure 4.31. The die set is attached to a carriage, which stays in the press and is constantly attached to the die accelerator. The interchangeable die is attached to both the top and bottom rails of the carriage, or in the case of spanking die, only to the bottom carriage. Aquick-acting clamp system and die-change roller tables makes it feasible to change dies in 1 to 2 min.

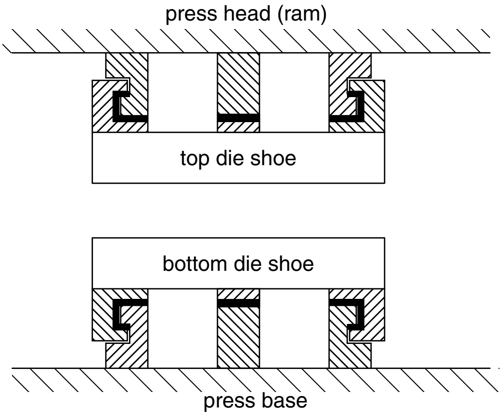


FIGURE 4.26 Press and die rails for wide dies.

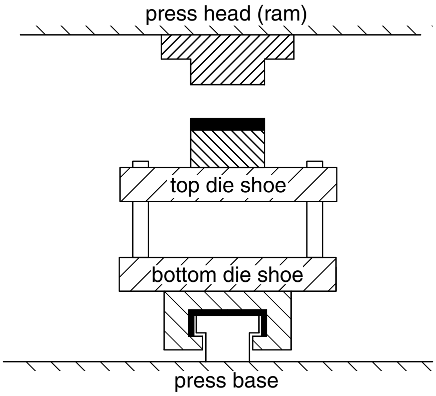


FIGURE 4.27 Spanking die attached to the bottom rails only.

4.6 Punching, Perforating, Notching, and Mitering

4.6.1 Definition

In the punching processes, a part of the material is removed by shearing from the body of the material. The removed part (slug) is scrap (Figure 4.32). These processes shall not be mixed up with blanking (stamping) when during a conventional press operation, the blanked (punched) out slug is the product, and the remainder of the strip is scrap. Blanking is not a process used in roll forming lines.

Punching, notching, mitering, and other press operations can be completed in either a loose or tight line.

4.6.2 Punching

Punching is occasionally and incorrectly called piercing. Piercing is achieved with special punches, which leave a hole in the material and flanging it without creating a slug (see Section 4.7.1).

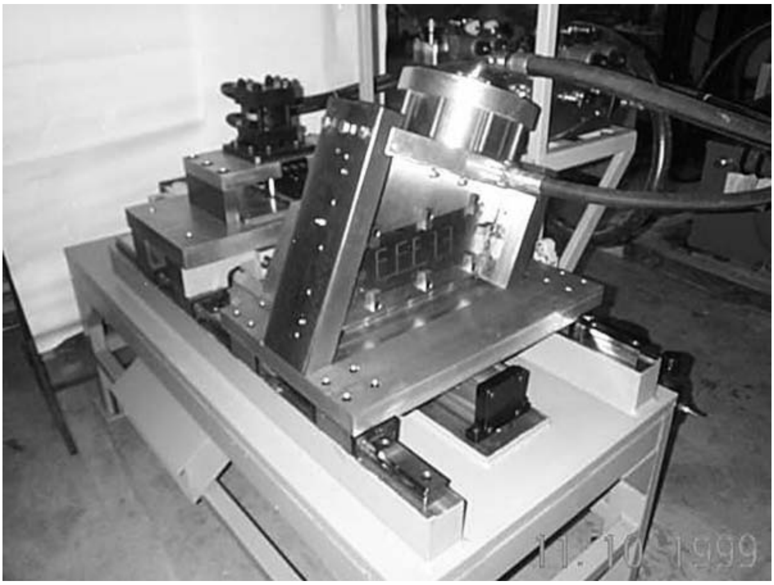


FIGURE 4.28 Self-contained hydraulic cutoff press/die combination. (Courtesy of CompuRoll Inc.)

4.6.3 Perforating

Perforating is punching a large number of small holes in a symmetrical pattern (Figure 4.33). Perforating requires special equipment and tooling; therefore, in most cases, the perforation is completed by outside contractors.

In some cases, a perforated pattern, micro-louvers or punched/embossed loops can be punched in-line (tight line or loose line) at high speed. Having this process included in the line could save considerably on the cost of buying and stocking preperforated coils.

4.6.4 Notching

Notching is a process where part of the strip edge (or cut end) is cut (sheared) out (Figure 4.34). Sometimes, punched holes cut through at a later stage (e.g., by the cutoff, etc.) appear as notches in the finished products (Figure 4.35).

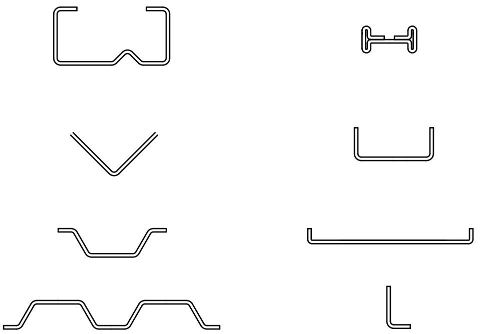


FIGURE 4.29 Separate cutoff dies are made for each of these sections.

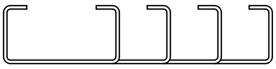


FIGURE 4.30 One die can cut a family of different section.

4.6.5 Mitering

Mitering is a punching or notching operation, which prepares the ends of the formed profile to fit for at a 90° (or other) bending assembly (Figure 4.36). This process is applied to make frames for pictures, windows, doors, and other products.

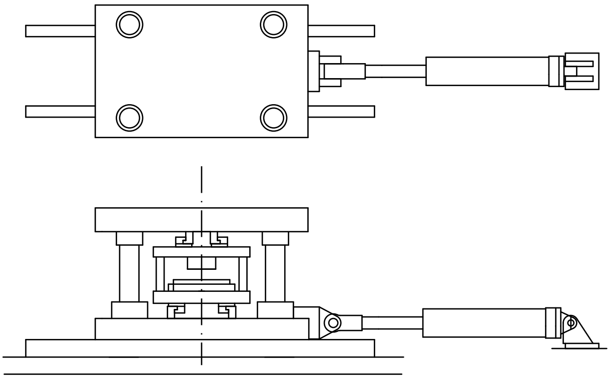


FIGURE 4.31 Quick-change die at perpendicular direction to the product flow.

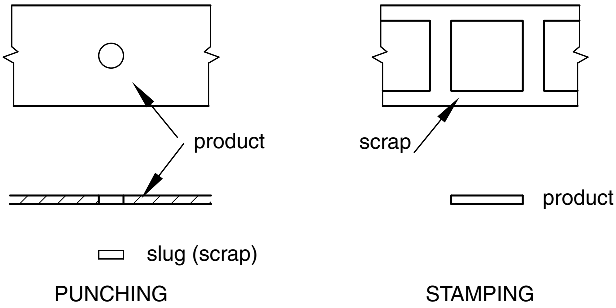


FIGURE 4.32 Definition of punching and stamping (blanking).

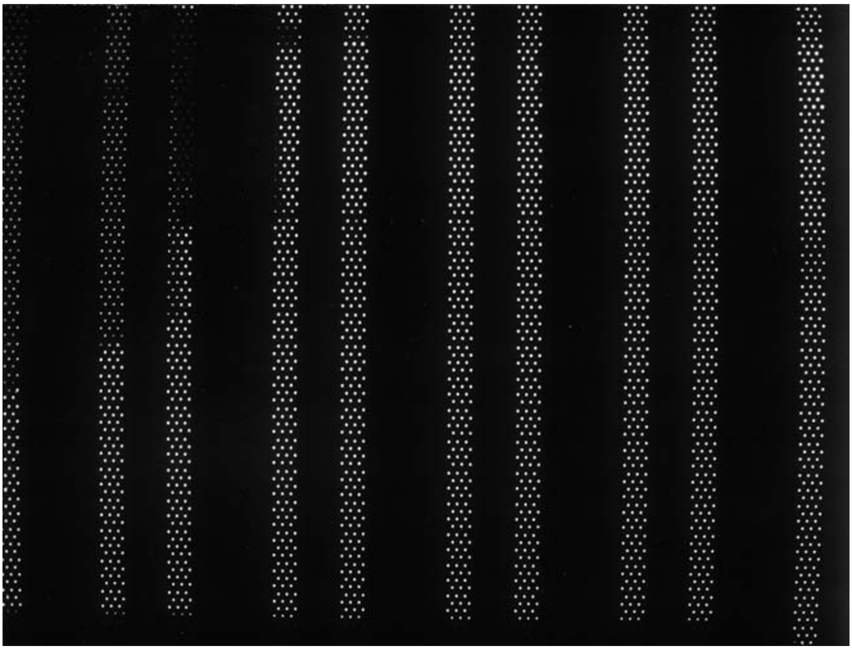


FIGURE 4.33 Perforated coil.

4.7 Piercing and Partial Punching

Piercing and partial punching do not generate slugs or cutouts, although they are considered punching operations using punching tools and dies.

4.7.1 Piercing

The usually pointed piercing tool penetrates through the metal, creates a hole, and forms the surrounding material out of its original plane (Figure 4.37).

4.7.2 Partial Punching

In the conventional punching operation, the punch shears through the material and the center part, the slug, is disposed off. In partial punching, the material is only partially sheared; the slug is retained by attachment to the strip. This method is most commonly used in fluorescent light shades. The slug can be knocked out or bent out where an opening is required for wires or for other reasons.

In another type of partial punching, the slug is retained around its full circumference. This method has been used to make skid-free surface (Figure 4.38) in an approximately 0.110-in. (2.75-mm) thick steel. The gap between the punch and the die can be considerably larger than the one used for conventional punching.

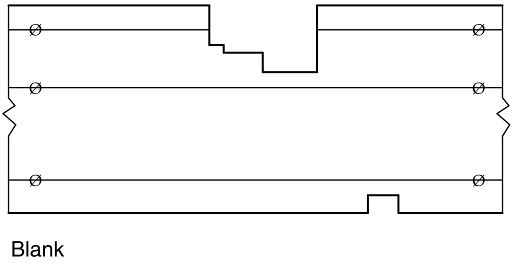


FIGURE 4.34 During notching the edge of the strip or product is removed together with the cutout part.

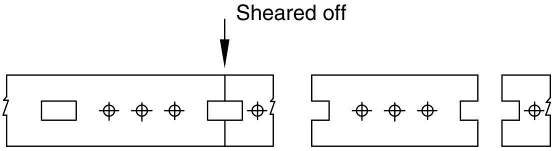


FIGURE 4.35 After shearing to length, punched holes may appear as notches.

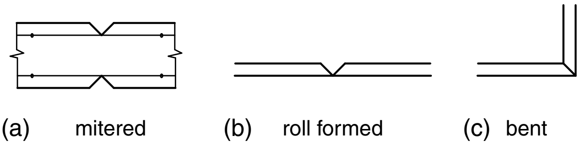


FIGURE 4.36 Mitering the strip for bent corners.

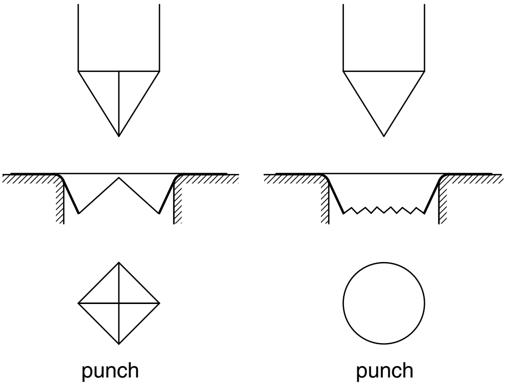


FIGURE 4.37 Piercing holes.

4.8 Flanging, Louvering, and Lancing

These operations involve partial or full cutting through the material and forming part of the strip out of its original plane. In a few cases, slug is also generated.

4.8.1 Hole Flanging and Dimpling

During flanging, part of the material (usually a circular slug) is removed and the adjacent material is stretch-formed or drawn. The flange can be cylindrical (Figure 4.39), conical (Figure 4.40), or other shape.

In some cases, the hole is punched and only some parts are bent (flanged) as shown in Figure 4.41a. In other cases, the length of the flanges is not uniform to ease the flanging operation (Figure 4.41b).

Dimpling is similar to embossing or drawing, creating a small displacement of the material, as shown on the right-hand side of Figure 4.42.

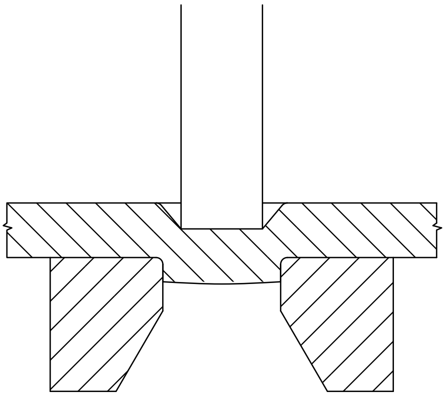


FIGURE 4.38 Partial punching creates dimples on the opposite side.

4.8.2 Louvering

In louvering (Figure 4.43), one or two slots are made in the material and one edge of the slit is embossed. This process is used to create ventilation opening or small locating stops in the finished products.

4.8.3 Lancing

Lancing is a process that often used to create protrusion for attaching other materials to the product such as wire (Figure 4.44a), wood (Figure 4.44b), plastic extrusion (Figure 4.44c), or other components (Figure 4.44d; see also Section 4.14.4 and Section 4.15.3).

Occasionally, slugs are punched out before lancing (Figure 4.45).

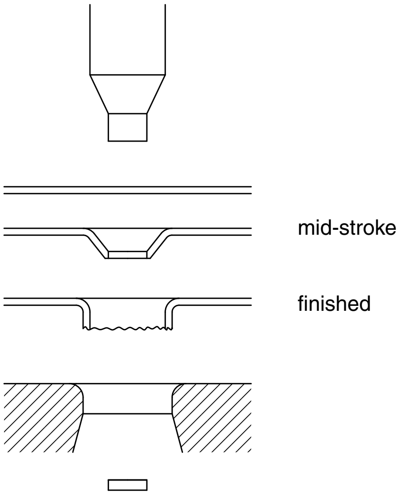


FIGURE 4.39 Hole with cylindrical flange.

4.9 Embossing and Drawing

During embossing and drawing, a part of the material is stretched out of its original plane without shearing.

4.9.1 Embossing

Embossing creates protrusions in the material. Usually, a blunt male punch penetrates into a die while stretching the material. Hold-down is usually not used but tool shoulders (or incorrectly called "strippers") may spank the edges of the embossments flat at the end of the stroke. The depth of the embossment is restricted by the mechanical properties of the material, and the thickness, embossment geometry, punch and die radii, lubrication, and other factors (Figure 4.46).

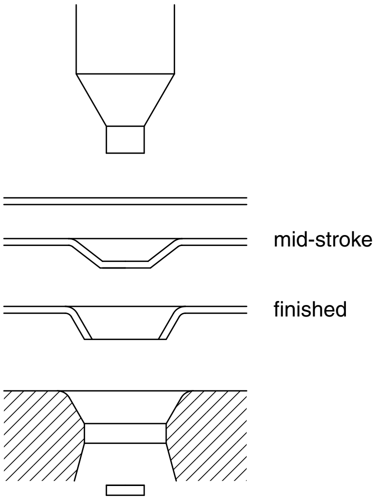


FIGURE 4.40 Hole with conical flange.

4.9.2 Drawing

Drawing is very seldom applied to roll formed products. However, drawn, decorative patterns are used in residential and garage doors to imitate a wood door-like pattern (Figure 6.15).

During the drawing operation, the material is held down by a blank holder to eliminate wrinkling around the drawn pattern. The metal must have sufficient ductility and strength to avoid cracks. Drawing is practically the only operation, which may require drawing quality starting material for a roll formed product.

In most cases, the drawing operation is performed before roll forming.

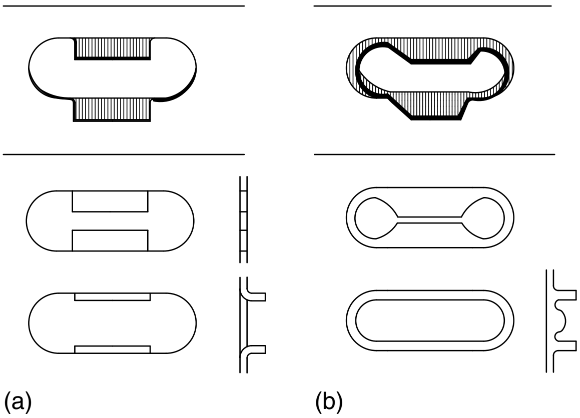


FIGURE 4.41 (a) Partial and (b) uneven flanges.

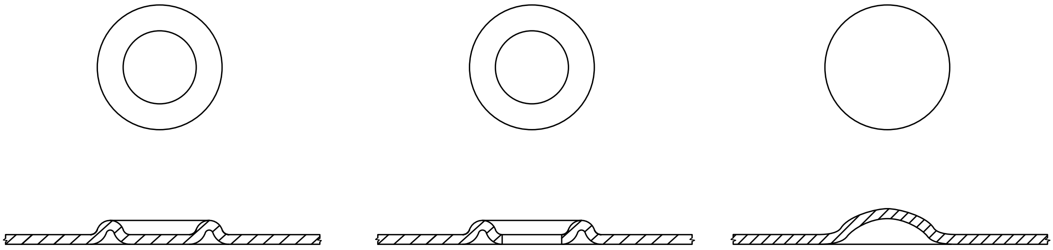


FIGURE 4.42 Ring embossment without hole, with hole and dome-shaped embossment.

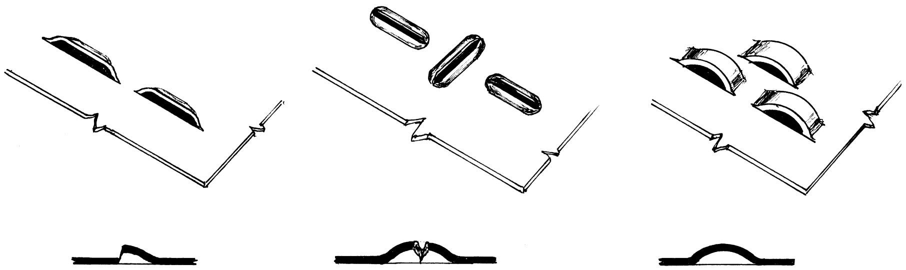


FIGURE 4.43 Louvers.

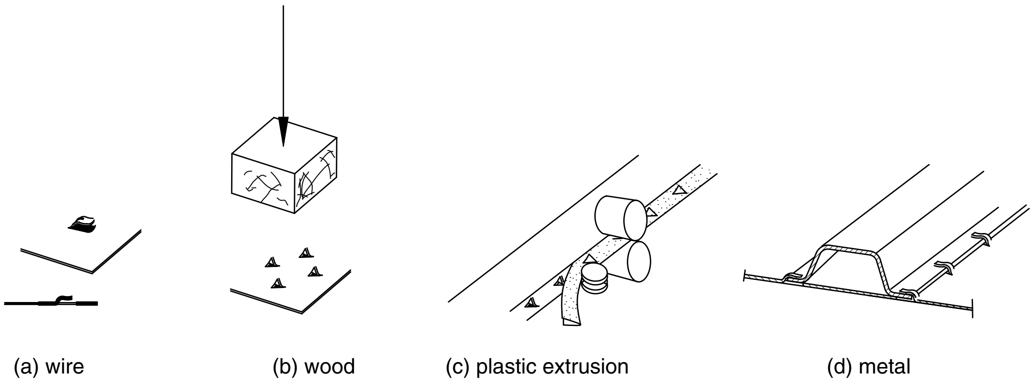


FIGURE 4.44 Different lances to hold wire, wood, plastic, metal, or other material.

4.10 Bending

Bending across the direction of roll forming is a requirement for many products. Typical examples are shelving and doors. The bends made in the secondary operations have a variety of cross-sections (Figure 4.47) and, in most cases, are perpendicular to the longitudinal bends made by roll forming.

The cross bends can be made in different ways.

4.10.1 Bending by Secondary Roll Forming

Roll forming 90° to the original roll forming direction (Figure 4.48) is a common procedure for some products. This process has two major limitations:

- If the cross-bend is made by roll forming, then space has to be provided for the roll run-out between the two perpendicular formed edges. This gap may weaken the product and therefore its application is limited (Figure 4.49).
- Parts may run skewed or wedge-in if roll forming in the cross direction has to

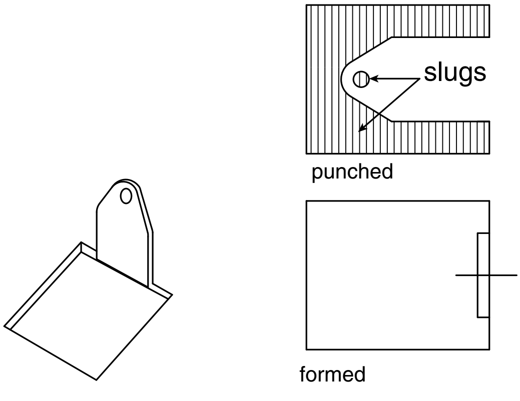


FIGURE 4.45 Punching and bending creates other types of lances.

be made on short but wide products (Figure 4.50a). Either good stationary guides or chain pushers can help to keep the product in right position throughout the second mill (Figure 4.50b).

4.10.2 Cutoff Die Bending

A single 90° bend can be made with the cutoff die at the lead end of one part and the tail end of the next part during the cut off process. The double shearing followed by the bending is accomplished in one stroke of the cutoff press (Figure 5.27).

4.10.3 Wing Bending

The operation of this equipment is similar to a hand brake or bending operation. Simple wing bender units can bend up to 90° or more one or both ends of the product (Figure 4.51). This method is frequently used for shelving and can produce one finished product approximately every 6 sec.

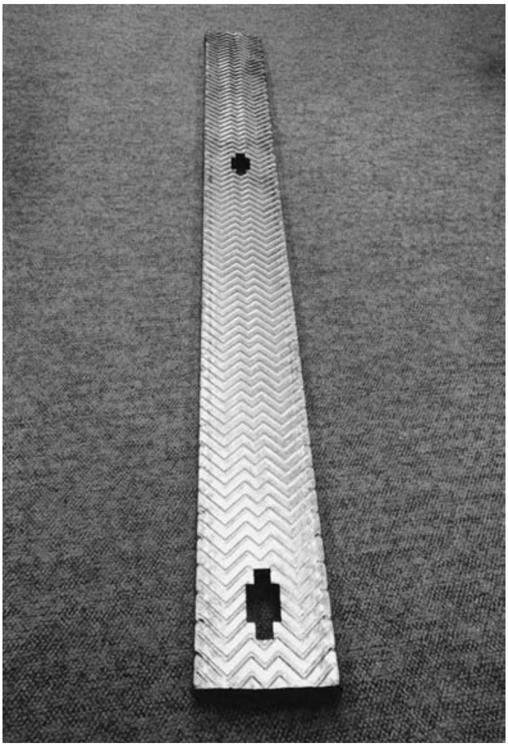


FIGURE 4.46 Embossed stiffener patterns. (Courtesy of Delta Engineering Inc.)

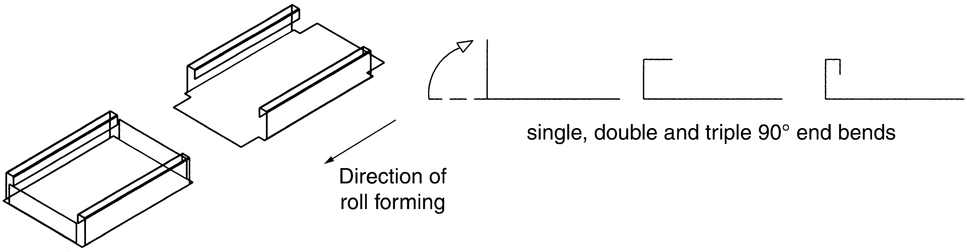

single, double and triple 90° end bends
Direction of roll forming

FIGURE 4.47 Single, double, and triple bends across the roll formed section.

4.10.4 Wing Bending Double Bends

If two or more 90° bends perpendicularly to the direction of rolling are required, then the bends can be made one by one, either in separate benders placed one after the other (Figure 4.52), or in a combined bending unit bending the tail end of the first product and the front end of the next product.

4.10.5 Wiping

Wiping can be used as an alternative method to wing bending to form the ends of the product at 90°. Wiping can be performed with blocks (Figure 4.53a–c) or with rolls (Figure 4.53d–f).

4.10.6 Wiping with Rolls

Wiping may mar the surface prepainted or high luster material. In this case, rolls can be used to wipe the ends. Wiping with rolls require a longer die travel (longer by the roll diameter) than wiping without rolls.

4.10.7 Complex Benders

Three or more bending motions are required occasionally to complete complex products in the line. Figure 4.54 shows one corner of a shelf, which requires two bends for the short end (perpendicular to the roll forming direction) plus a 90° bend of a tab. The tabs are resistance welded to the end bends to provide a strong, closed corner.

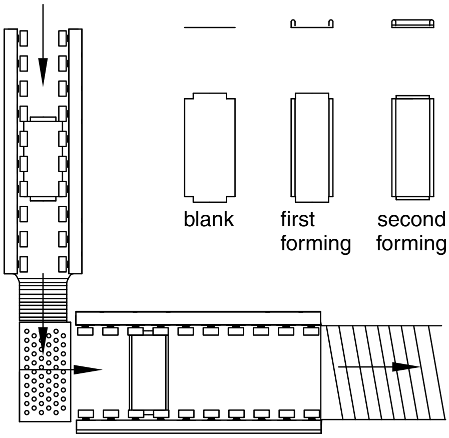


FIGURE 4.48 Roll forming bends 90° to the original forming direction.

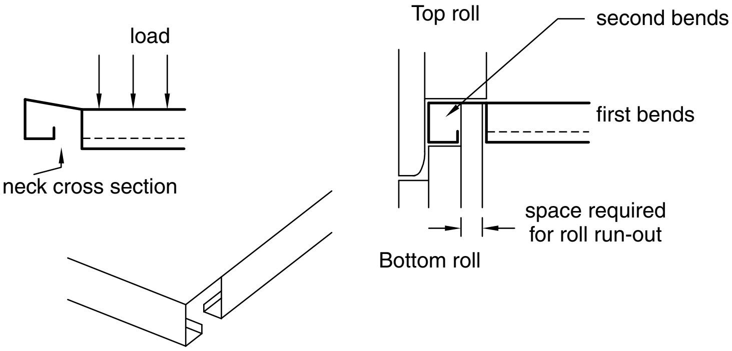


FIGURE 4.49 Gap required for the 90° across roll forming can reduce the strength of the product.

4.11 Curving (Sweeping)

4.11.1 General

A basic feature of the roll forming process is to bend the starting flat strip in a straight line in the longitudinal direction. However, the final shape of large number of roll formed product is not straight but curved. Hot-rolled sections, such as angles, “U” channels, “I” beams, as well as sheets, plates, and extrusions are curved after being cut to length. Roll formed products can also be cut to length and curved after cutting to length, but it is usually more economical to curve them continuously in the line, and then cut them to length after forming. In many cases, the continuous curving is the only way to manufacture parts economically.

The automotive industry uses the term “sweeping” instead of the widely used term “curving.” In curving, the magnitude of curvature is defined by the curving radius, and in sweeping by the sweep number. In this book, the term “curving” is used, except for some specific automotive applications.

In the curving process, the finished, rolled products are formed to a specific radius, in one plane (two axes) as shown on Figure 4.55. In the spiraling process, the rolled product is curved in three axes (to form a spiral as it is schematically displayed in Figure 4.56).

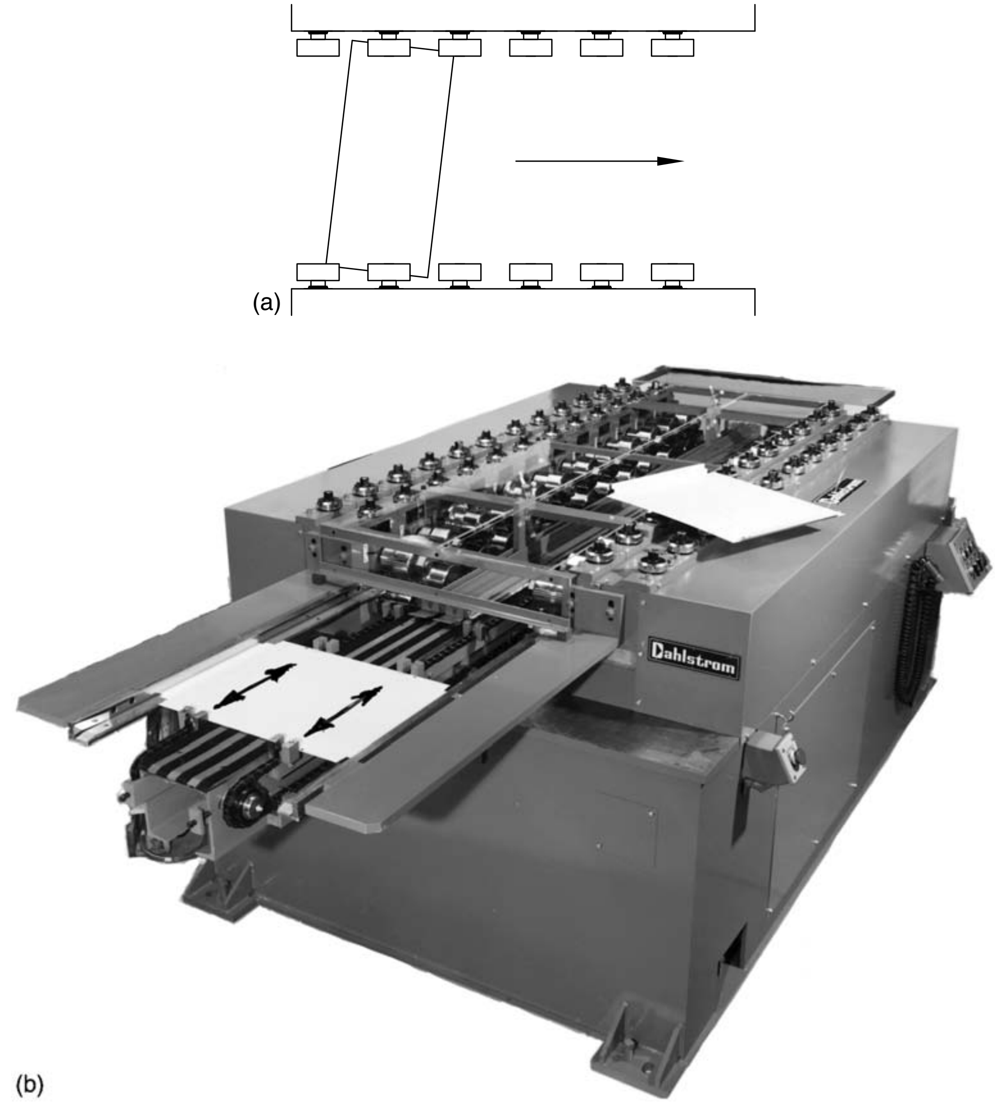


FIGURE 4.50 (a) Short and wide pieces can get wedged in the mill; (b) chain-mounted fingers (see arrows) eliminate this problem. (Courtesy of Dahlstrom Industries.)

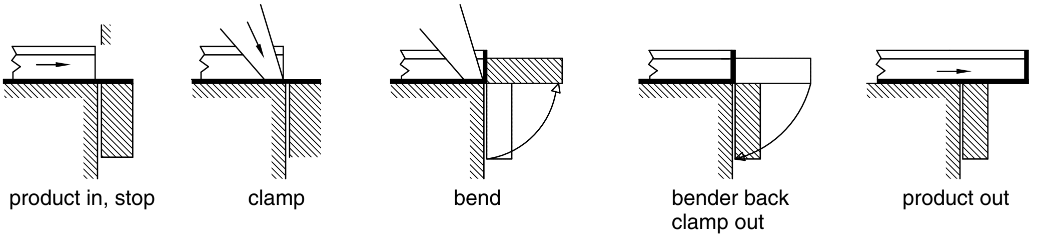


FIGURE 4.51 Wing bending one 90° bend across the part.

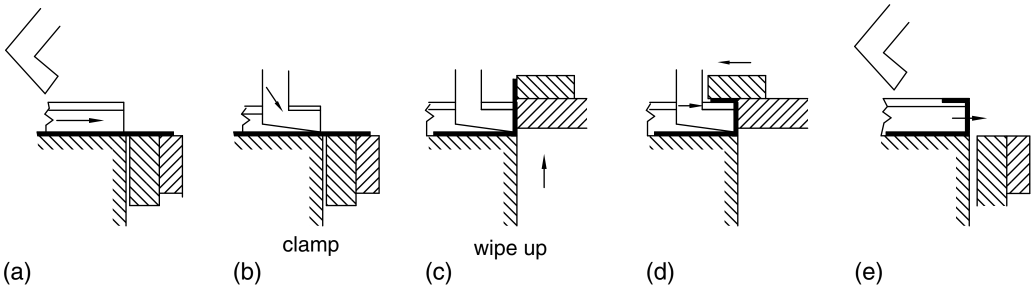


FIGURE 4.52 Wing bending two 90° bend across the part.

4.11.2 Correlation between Design for Loading and Curving of Roll Formed Products

During curving, the stresses must exceed the yield stress to create permanent deformation. When curving is made with rolls, the area of load is concentrated in a line (Figure 4.57). This creates very high concentrated loads, but curving must be achieved without local buckling, web crippling, twisting, or other imperfections. Curving products with holes, notches, and dimples is even more difficult and complex.

To create a permanent curvature, the product must be stressed beyond yield point, into the plastic range. The inside part of the section, more or less between the neutral axis and the center of curving radius, will be permanently shortened

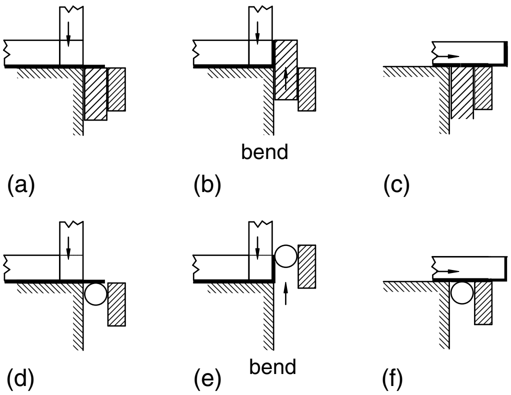


FIGURE 4.53 Sequence of wiping 90° bends across the part with blocks (a, b, and c) or rolls (e, f, and g).

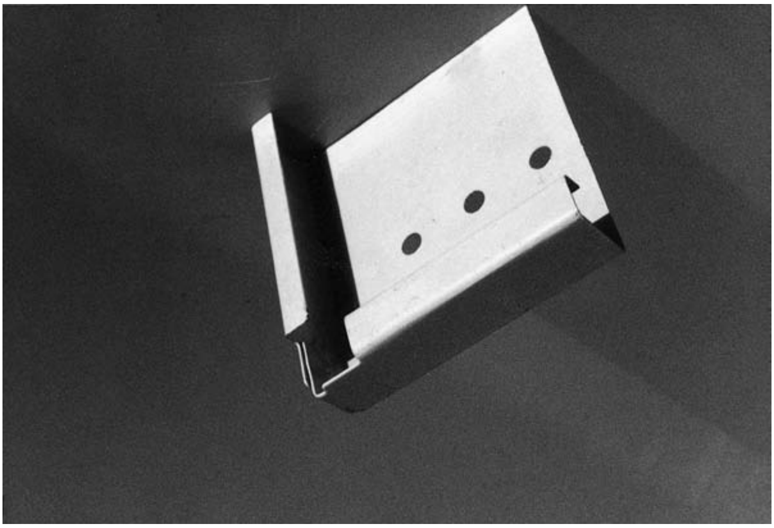


FIGURE 4.54 Complex corner bends for shelving.

(compressed) and the outside part of the section will be permanently elongated (stretched). As the material content does not change, the compressed part of the section will become thicker, and the stretched, outside part will become thinner (Figure 4.58). Therefore, the cross-section deforms and the neutral axis moves closer to the inside during curving as a result of stresses developed in the thicker and thinner sections. This effect is described in a later part of this section. The friction between curving dies and products, the stiffness of product, and the behavior of material will also contribute to the change in the position of neutral axis.

In the case of sections asymmetrical to the curving plane, twist will also develop (Figure 4.59). The stretched, outside part of the section usually presents fewer problems. Stresses seldom exceed the ultimate tensile stress because the part is pushed and pressed through the curving die, unless the punched holes and notches significantly reduce the cross-section of the outside section. The limiting factors to curve product to a smaller radius will usually be the buckling of the inside part (Figure 4.57b and Figure 4.60), the crippling of the web, the twisting of the section, or other product deformation.

The roll geometry (diameter, position, and distance of rolls) will also have an effect on buckling. This effect will be discussed in a later part of this section.

Another restriction on curving is web crippling. An analogue with the I beam explains web crippling. The strength of a section (assuming the same cross-section area) will be increased by increasing the distance of the material from the neutral axis (Figure 4.61). The distance cannot be increased to infinity since over a certain limit the web will be too thin and will cripple under the load.

Figure 4.62 shows some examples of web crippling and section deformation under concentrated forces. Inclined forces created by a deformed web may induce additional flange crippling. This effect makes any attempt to calculate stresses even more complex.

The effect of other factors on curving, such as stiffeners, type of corrugation, bending radius of the section, holes, cutouts, closed sections, section asymmetricity, physical properties of the material, lubrication, and bending equipment will be mentioned later in this section.

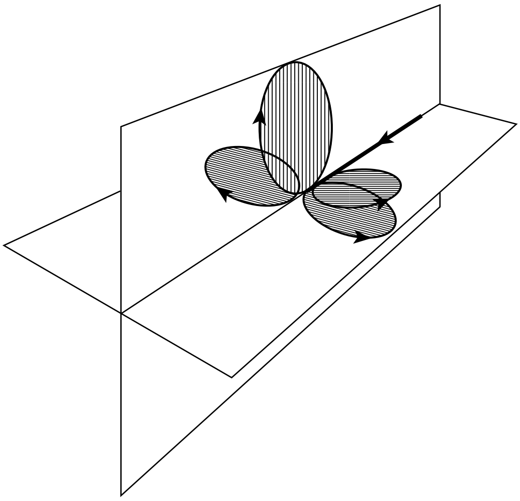


FIGURE 4.55 Curving is in one plane.

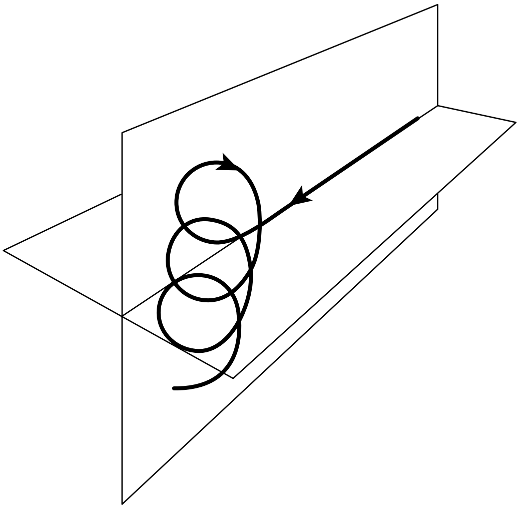


FIGURE 4.56 Spiraling.

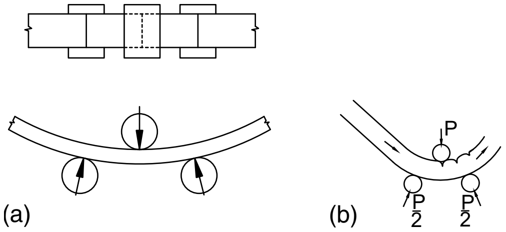


FIGURE 4.57 Curving with rolls create concentrated load at the contact line.

4.11.3 Minimum Curving Radius

The minimum radius of a curved product is limited by the physical characteristics of the material (yield and ultimate strength, elongation, work hardening), the compression stiffness of the section (resistance against buckling while pushed into the curving tools by the roll former) the shape, the height to thickness ratio, and sensitivity to surface marks. Consequently, the smallest curving radius usually can be established only by tests, after the curving tooling is completed.

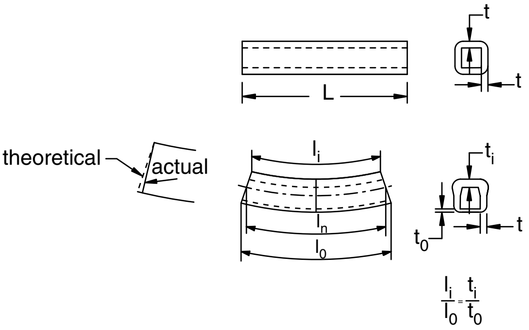


FIGURE 4.58 The inside of the curved part is thicker, and the outside is thinner.

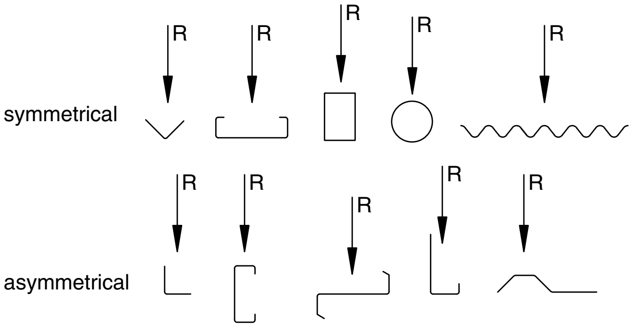


FIGURE 4.59 Section asymmetrical to the curving plane will develop a twist.

When a rectangular, flat bar is curved edgewise (Figure 4.63), then theoretically the neutral axis remains in the middle of the section; the compression stresses at the inside fiber are equal to the tension stresses at the outside fiber. In reality, the compression of the inner fiber thickens the material, while the outside fiber is getting thinner. Therefore, the true stress at the inside will be smaller and at the outside larger. The larger outside stresses will elongate the material more and make it even thinner. At the same time, the thicker inside fiber the true stresses can actually decrease, thus stopping further change in thickness.

As an effect of these changes, created by the true stresses, the neutral axis is gradually moving towards the inside. This hypothetical phenomenon is similar to the moving of the neutral axis in the direction of the bending radius during brake and roll forming.

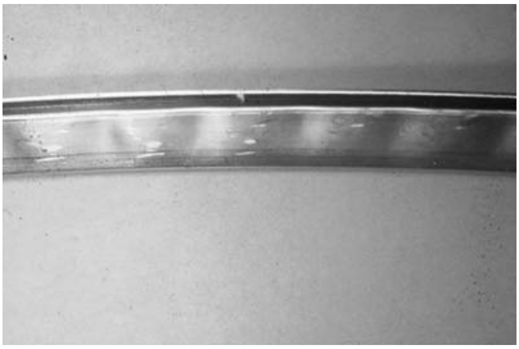


FIGURE 4.60 Buckling of the inside of the curved part.

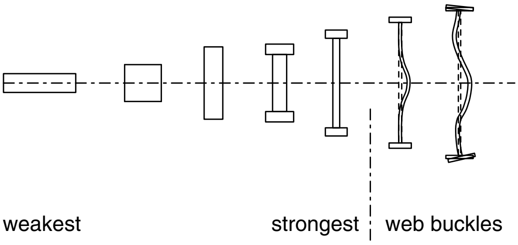


FIGURE 4.61 Web buckling of I beam.

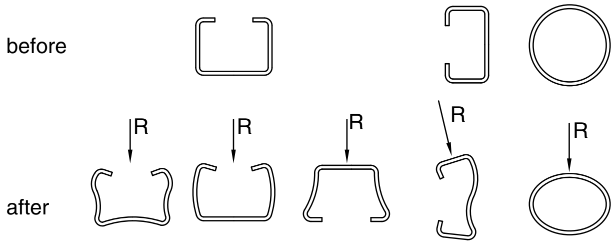


FIGURE 4.62 Typical web buckling (crippling) of different cross-section.

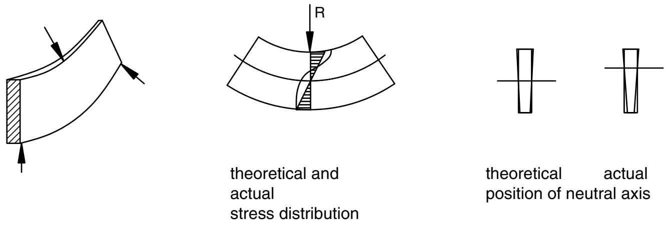


FIGURE 4.63 Curving rectangular bar edgewise.

The theoretical strain of the outside fiber during curving (Figure 4.64) is

$$D_0 \times \pi - D_n \times \pi = \pi(D_0 - D_n)$$

$$D_0 - D_n = h$$

$$\text{Total elongation} = \pi\, h$$

$$\begin{aligned}\text{Percentage elongation } e &= \frac{\pi h}{D_n \pi} \times 100 \\ &= \frac{h}{D_n} \times 100\% \end{aligned} \qquad (4.1)$$

In other words, the theoretical elongation of the outside fiber equals to the ratio of the section height divided by the radius of neutral axis. Because under actual conditions, the neutral axis is moving closer to the center of the curving radius, the actual elongation (strain) on the outer fiber is larger than the theoretically calculated value. On the other hand, the compression from the roll forming mill, pushing the section through the resistance of the curving tool, marginally increases the compression stress in the section. This effect is not very significant because the stress created by the pushing is considerably below the yield stress.

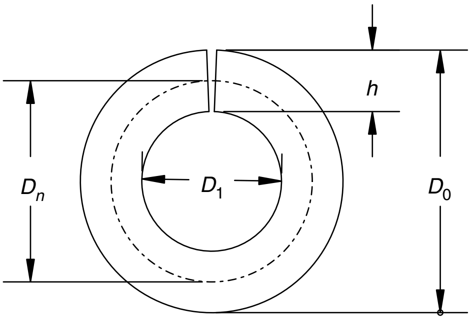


FIGURE 4.64 Theoretical approach of calculating stresses in a tubular part.

As an example, take a 2-in. (50-mm) deep section, made out of 0.030-in. (0.75-mm) thick material, curved into 11-in. (280-mm) diameter. This results in an approximately 10-in. (25-mm) neutral axis diameter, creating a (2(10) × 100 = 20%) theoretical elongation in the outer fiber and 40% compression in the inner fiber. To achieve this, the outside fiber must be exposed to permanent elongation of over 20%, without necking (see stress–strain diagram in Figure 6.4). At the same time, the inside of the thin section must be compressed by 20% without wrinkling (buckling). Considering the increased strain on the outside fiber caused by the movement of the neutral axis towards the center of the curving radius, to curve this deep section to the specified radius will be extremely difficult, if not impossible.

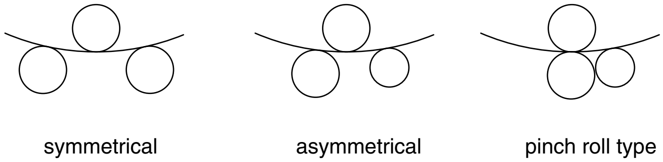


FIGURE 4.65 Three-roll curving units.

4.11.4 Curving Precut Parts Separately

Precut sheets, plates, hot-rolled, or roll formed sections must be curved with driven curving units. Typical arrangements, where material is moved by the curving rolls, are the symmetric or asymmetric pyramid or pinch roll type three-roll curving (Figure 4.65), four-roll units (Figure 4.66), or two-roll curving equipment with elastic roll (Figure 4.67).

Curving precut parts is labor intensive, and both the front and the tail end of the curved product remains straight (Figure 4.68). The length of the straight section depends on the geometry (roll distance and roll diameter) of the curving unit. Curving precut parts with curving shoes is not practical.

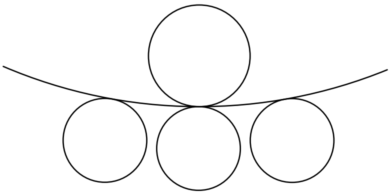


FIGURE 4.66 Four-roll curving unit.

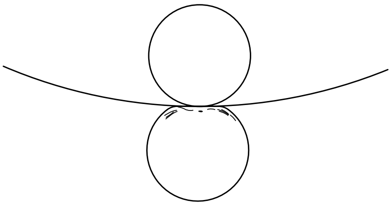


FIGURE 4.67 Curving with elastic (bottom) roll.

4.11.5 Curving in Roll Forming Mill with Rolls

In the case of roll forming, the product is continuously pushed through the curving tooling by the roll forming mill. Figure 4.69 shows two possible methods of curving without additional curving stands. These methods can be used for products with relatively large curving radii.

Curving, however, is more frequently carried out with a separate three-roll unit attached to the end of the mill. In case of continuous roll forming, the curving rolls are usually not driven. To avoid, or at least minimize, the chances of product buckling between the last pass of forming rolls and the curving tools, the two units should be located as close to each other as possible. As an alternative solution, the product could be supported all around to avoid buckling. The process of removing the last piece (end of coil) from a nondriven curving units must be considered at the design stage.

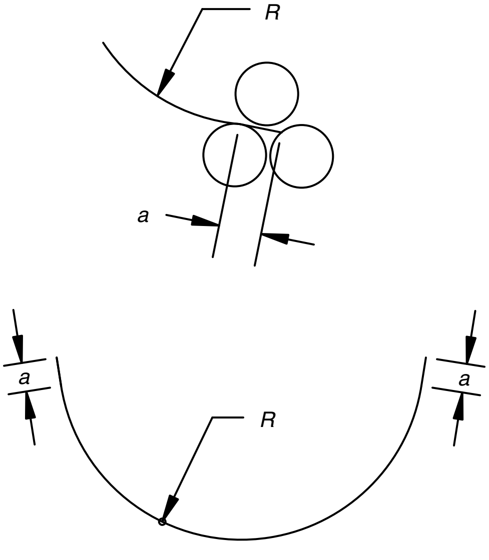


FIGURE 4.68 The front and tail ends of precut parts, curved in a three-roll curving unit, remain straight.

The application of standard, three-roll, pyramid-roll curving mechanisms with center roll adjustment for radius should be avoided. Figure 4.70a shows the incorrect, two-way bending created by this type of unit. The preferable method is to adjust curvature with the third roll only (Figure 4.70b).

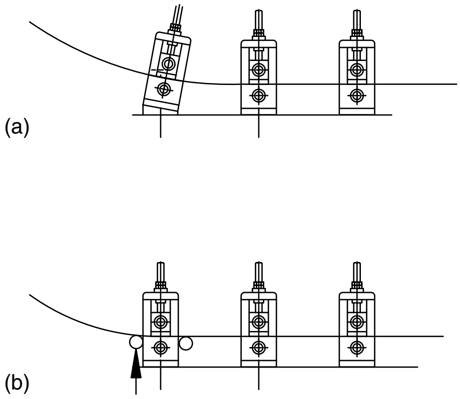
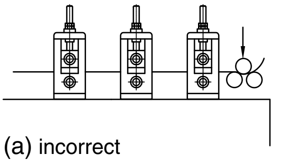


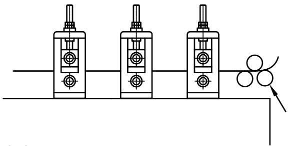
FIGURE 4.69 Continuous curving in the roll forming mill.

As mentioned before, owing to compression and curving die pressure, buckling is the most frequent limiting factor when light-gauge products are curved. Buckling is influenced by many factors. Improving the curving conditions will allow curving products with considerably smaller radii.

The effect of some of the influencing factors can be explained by reviewing curving of simple corrugated panels. The term "minimum curving radius" refers to the smallest radius to which a roll formed product can be curved without developing undesirable deformation which can be harmful to the strength or degrading to appearance from a specific material with given curving equipment.



(a) incorrect



(b) correct

FIGURE 4.70 Incorrect (a) and correct (b) application of a three-roll curving unit attached to a roll former.

4.11.5.1 Thickness

The thinner the material, the larger the minimum curving radius will be because it is more difficult to compress thin material than thick material.

In a close-centered, three-roll curving unit, the variation in thickness, even within one coil, will change curving radius (increase in thickness will reduce the curving radius as shown in Figure 4.71).

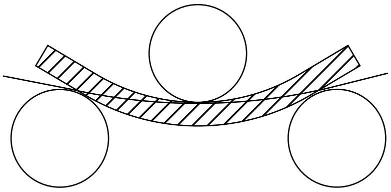


FIGURE 4.71 Effect of material thickness change to curving radius.

4.11.5.2 Height

The higher the section is, the larger the minimum curving radius. The relation between section height (H), curving radius (R), and material thickness (t) is shown in Figure 4.72 [417].

4.11.5.3 Product Shape

The larger the flat, compressed areas, the more prone will be the section for buckling.

4.11.5.4 Bending Radius

Products with larger bending radii, especially in the compressed part of the section, can be curved to smaller radius. For example, if a 1/2-in. deep sinus corrugated section (shown in Figure 4.73) can be curved to, say, a 10-in. (200-mm) radius, then a 1/2-in. deep section with sharp corners formed from the same material may be curved only to 200 in. (5000 mm) without buckling.

It follows that a section with curved inside and straight outside surfaces can be curved close to the same radius as the fully sinus corrugated panel (Figure 4.74).

In other words, sections with large inside bend radii (inside refers to the part of the section closer to the center of curving radius), with no or minimum flat inside surface, can be curved to a small radius (Figure 4.75).

4.11.5.5 Effective Stiffener Ribs

Because the buckling develops in the compressed (inside) surfaces, stiffener ribs in these areas can help to reduce buckling. Panels with longitudinal stiffener ribs will have a better chance to be curved to smaller radii than panels without these ribs.

4.11.5.6 Matching Curving Tool and Profile

Curving roll pressure can also create or contribute to buckling. Therefore, it is important that rolls, which exert great pressure, should conform to the full surface of the section, and not just touch it at a few points (Figure 4.76).

Occasionally, the bending radius of the roll formed product is larger than the matching radius on the male curving roll (see Figure 4.77a). This mismatch can be the result of incorrect setup, worn forming rolls, or using new or incorrectly designed curving rolls. The reforming of the bend lines by curving rolls with different radius will result in distorted products. Too large a radius on the female die can have equally detrimental effects (Figure 4.77b).

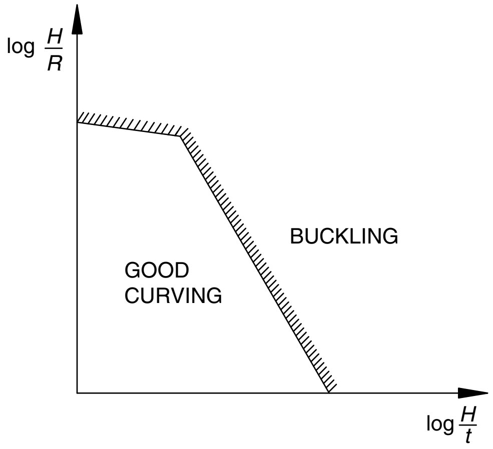


FIGURE 4.72 Effect of height and thickness on curving.

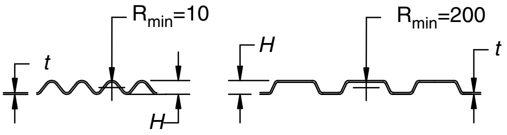


FIGURE 4.73 It is more difficult to curve products with a flat inside surface than with a radiused one.

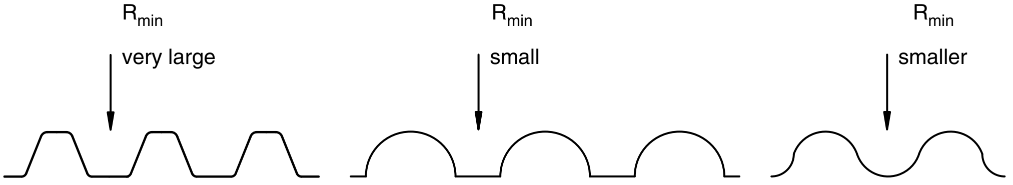


FIGURE 4.74 Products with curved inside elements can be curved to smaller radius.

4.11.5.7 Product Width (Coverage)

It is important that the roll formed profile should match the curving die exactly. Curving dies not matching the roll formed profile may completely reform the product. The result will be a straight product edge instead of a curved one (see Figure 4.78).

If, on the other hand, the two edges of the finished panel are curved to the correct radius, but the center is straight or has a very large radius, then this problem is most probably caused by an excessive deflection of the curving roll shafts (Figure 4.79).

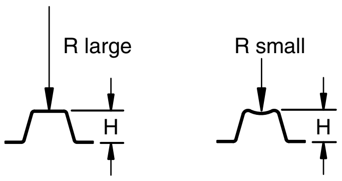
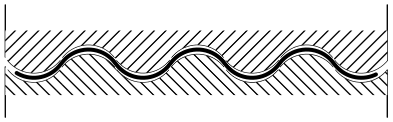


FIGURE 4.75 A small change in product design can help reducing minimum curving radius.

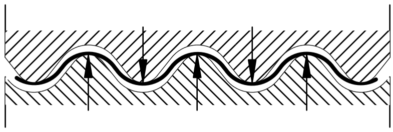
4.11.5.8 Center Distance of Curving Rolls

Most products will have less of a chance to buckle if the curving rolls are closer to each other (Figure 4.80). The bending moment required for permanent deformation is the result of the force on the curving roll multiplied by the distance from the next roll. The closer the rolls are (the smaller the distance is), the larger the forces are required to generate this bending moment (M_c) $M_\mathrm{c} = aP_a = bP_b$. The smaller the distances "a" and "b" are, the greater P_a and P_b forces are required.

The larger the curving forces are, the larger the shaft diameters required. The diameter of the curving rolls placed on larger shafts will be also larger. The larger the rolls are, the further they have to be placed, which contradicts the first requirement of putting the rolls as close as possible.



(a) Full line contact with rolls



(b) Point contacts with rolls

FIGURE 4.76 Full contact between the product and curving rolls reduces buckling.

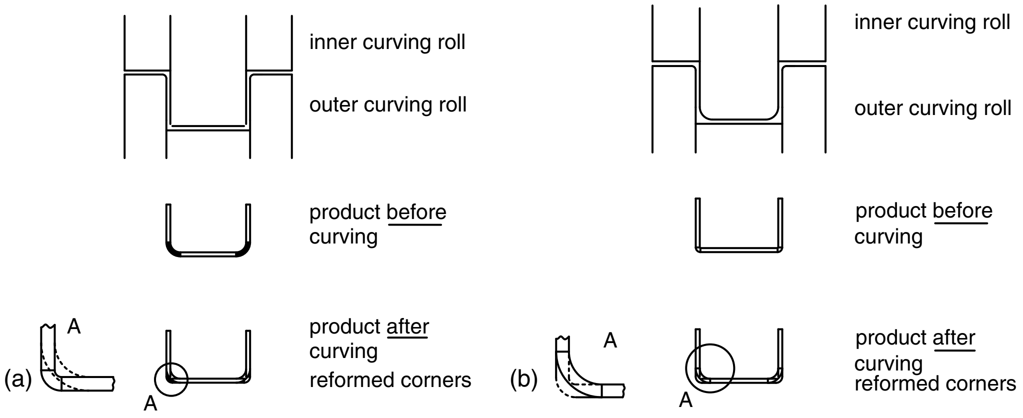


FIGURE 4.77 Nonmatching curving tool radius and bend radius will distort the product.

To find the optimum solution, sometimes either the minimum curving radius has to be compromised or curving shoes have to be used. Curving shoes will be discussed in a later part of this section.

One way to compromise forces and diameters is to have an asymmetrical curving roll arrangement, as shown on Figure 4.81. For example, if $a = 6.4$ in. (160 mm) and $b = 0.4$ in. (10 mm) and the diameter of "B" roll is 8 in. (200 mm), then the forces on the "A" roll will be 1/16 of the forces on the "B" roll. This will allow a small shaft and a small "A" roll, thus minimizing the "a" roll distance.

4.11.5.9 Effect of Inside Curving Roll Diameter

The curving roll diameter has little effect on buckling because during curving the roll contacts the product only in a line (Figure 4.82). In special cases, however, when the product is literally wrapped around the inside roll, the chances of buckling can be reduced (Figure 4.83). However, if the product is curved over 180°, then its removal can be tricky.

4.11.5.10 Elastic Outside Pressure Roll

Figure 4.84a shows how the above-mentioned wrapped around effect can be achieved using a rubber, urethane, or other elastic outside roll. Using elastic roll can minimize or eliminate buckling caused by

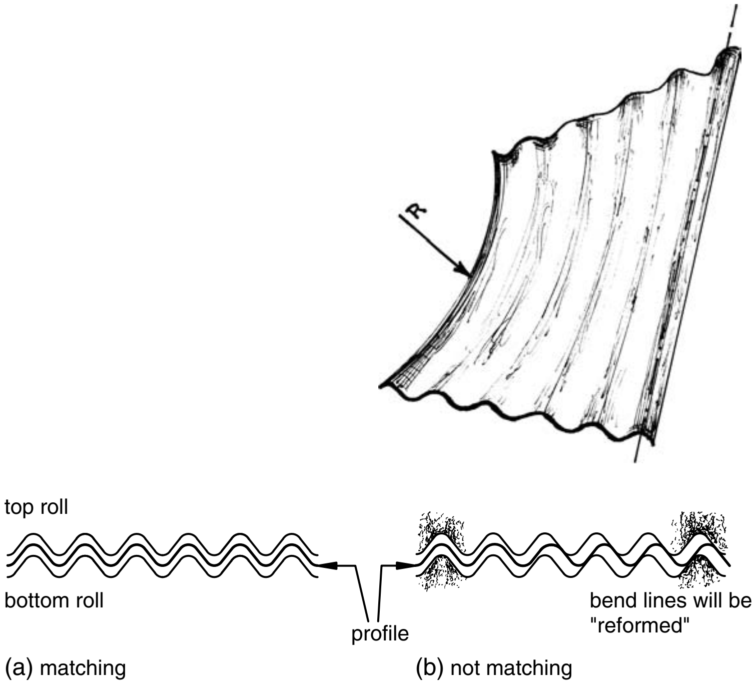


FIGURE 4.78 One edge of the curved panel can be straight if the product profile does not match the curving rolls.

holes and notches. To reduce the effect of the variation in shape caused by the fluctuation in material thickness and properties, it is advisable to use an additional steel radius controlling roll (Figure 4.84b).

When elastic curving roll is installed in a roll forming line, it should not be placed directly under the top or over the bottom curving roll to avoid curving the product at first in the opposite direction (Figure 4.85).

4.11.5.11 Buckling and Bending of Flanges

Compressed flanges have the tendency to buckle. The simplest way to minimize the effect of buckling, thus curving the product to a smaller radius, is to add a stiffener bend or rib to the flange as shown on Figure 4.86. If the product design cannot be modified, then we recommend enveloping the flanges (legs) in the curving rolls in an area as large as possible (Figure 4.87). At the same time, the entry of the leg (flange) into the enveloping slot should be facilitated. Ironing out of the buckled flange creates considerable friction and tool wear. Therefore, the flange rolls should be made from high-quality, wear-resistant tool steel, and rolls should be split at the anticipated wear line. Split rolls can be easily remachined and reconstituted to the original shape.

In case of curving channels with legs out, the outside fiber of the flanges will have considerable tension. The tension tries to pull the legs either out or in as shown Figure 4.88. After bending in or out, the outside fiber of the leg will be closer to the center of curving, thus having a smaller circumference, which results in a smaller tension. The tendency of having the legs bent in (or out) increases when the curving radius is reduced, when the leg is longer, when the material is thinner, and the further the angle is from 90°. Good flanging rolls or sometimes additional rolls can minimize this bending out (or in) tendency.

4.11.5.12 Sections with Hidden Bend Lines

Bends made during roll forming provide the strength and stiffness of the section. Therefore, it is best to curve a section with the curving rolls in contact with the bend lines. To illustrate this statement, let us take a "hat" section and a "C" section made from the same material, same blank size, same thickness, and formed to similar dimensions. Both sections with have the same inertia and section modules, and will be curved to the same radius. The two sections are shown on Figure 4.89. The center curving roll of the C section (Figure 4.89b) cannot touch the "hidden" corners; therefore, during curving, it can distort the shape. Therefore, a hat section (Figure 4.89a) can be curved to a smaller radius than a similar C section. Generally speaking, it is difficult to curve any section where the curving tool is not touching the bend lines. To overcome this problem, frequently curving shoes are applied instead of rolls (see Section 4.11.9).

4.11.5.13 Fully Closed Sections

Fully closed, welded sections give a good chance to be curved, although bend lines cannot be reached in the inside. Experience shows that it is relatively easy to curve some of the welded, shallow sections, such as bicycle rims. In the case of a small curving radius or thin wall thickness, deformation typical of tubes curved in conventional ways will prevail as shown in Figure 4.90. Mandrels, used in precut tube bending, are sometimes applied to eliminate buckling.

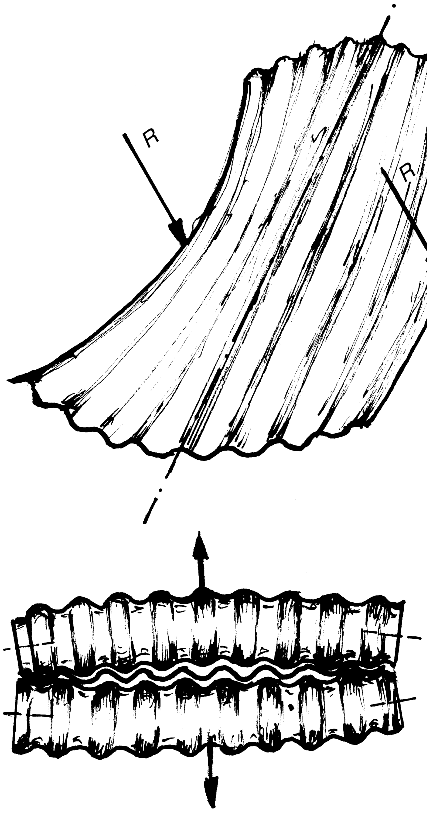


FIGURE 4.79 Too weak curving rolls will bend, yielding products with two curved edges and a straight center.

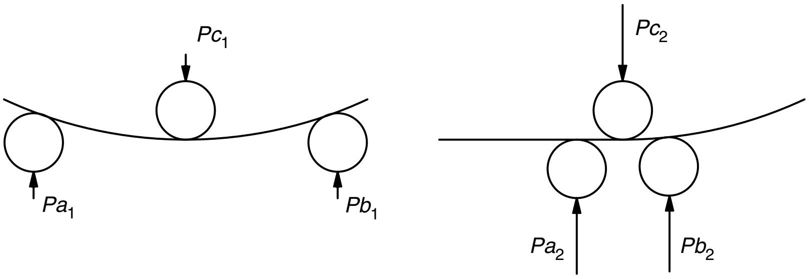


FIGURE 4.80 Short distance between curving rolls reduces the buckling tendency but increases the forces.

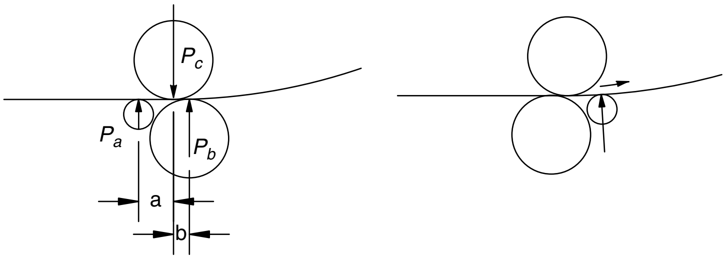


FIGURE 4.81 Asymmetrical roll arrangement may provide the smallest curving radius.

Nonwelded, closed sections can be also curved, but the minimum curving radius can be influenced by the deformation of the cross-section. Figure 4.91 shows a few typical curved, closed sections with various degrees of curving difficulties.

4.11.6 Curving Asymmetrical Sections

Compared with symmetrical sections, it is more difficult to curve sections that are not symmetrical to the plane of curving The stressed and compressed elements of the cross-section more or less balance each other in a symmetrical section, but they will deform asymmetrical section. The difficulties to curve asymmetrical, thicker walled, hot rolled sections are well known. In both hot rolled and roll formed cases, the simplest way to minimize problems created by the unbalanced residual stresses is to add additional rolls to the curving unit.

4.11.7 Curving by Controlled Buckling

Buckling of curved products is unsightly and unacceptable. Curving by preplanned corrugations, however, is one of the first and simplest methods used by tinsmiths (Figure 4.92).

Roof hip caps made from roll formed panels have been curved in a similar fashion, using multiple press hits. Building siding sheets are also curved to relatively small radii by multiple press hits (Figure 4.93).

Continuous curving by cross-corrugation is used to manufacture arched building components. Sections up to 7 to 8 in. (175 to 200 mm) in depth have been curved in this way by using presses or curving rolls (Figure 4.94).

It is important that during curving, the original bend lines should not be distorted [233]. Bend lines distorted by the curving press die can reduce the strength of the section by as much as 35 to 40%. The preservation of the longitudinal roll formed bend lines is critical to all curving process.

4.11.8 Spiral Forming

Rings and many other circular products are frequently made to exit from the curving mill in a slightly spiral way to simplify cutting. If the spiral (helix) angle of these products is small, and the

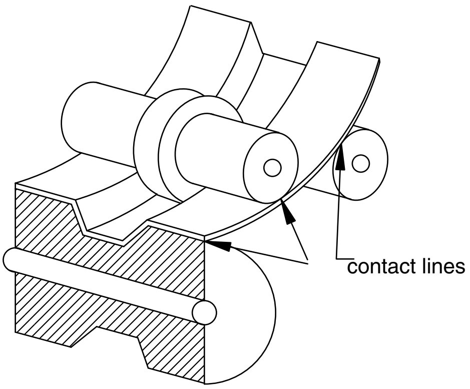


FIGURE 4.82 Curving rolls contacting the products in a line only.

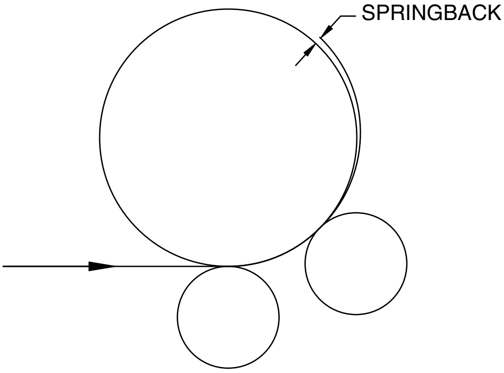


FIGURE 4.83 In special cases, the product is wrapped around the male roll.

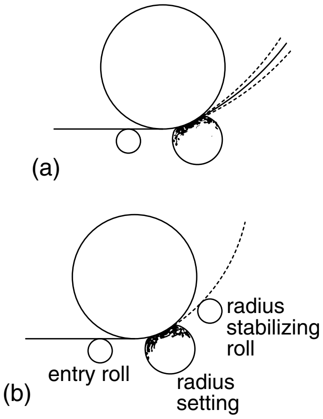


FIGURE 4.84 Radius stabilizing roll (b) can reduce radius fluctuation (a) when elastic roll is used for curving.

stresses in the material remain below the elastic limit, then the product springs back to the circular shape after cutting to length.

The spiral forming of flat and formed sections for pipes has been well known for a long time. The great advantage of the helical pipe manufacturing method is that by changing the helix angle, an infinite number of diameters can be produced from the same starting blank width (Figure 4.95). The smallest pipe diameter is usually limited by the joint strength, while the largest diameter is limited by the stiffness of the pipe wall and the available space. Joints are usually lock seamed or welded.

Smooth walled ventilation pipes, flexible electrical conduits, and flexible water hoses can be curved with shoes.

The spiral curving of corrugated culvert pipes is accomplished by three sets of curving rolls. The angle of the rolls is adjustable to suit the helix angle, while the corrugation pitch distance is automatically kept the same (Figure 4.96).

4.11.9 Curving with Shoes or Plugs

To curve roll formed sections with rolls is simple, but buckling, crippling, or twisting of the section restricts the minimum curving diameter. To curve products to smaller diameters, at room temperature, curving shoes or plugs are required.

Curving shoes usually envelop the full cross-section and force the part to curve. One set of shoes is required for each diameter. Shoes are not adjustable or may have a limited adjustability if made out of segments. The curving shoes can be expensive, but in many cases, the shoes provide the only route to curve the product to the specified, small radius.

Curving shoes must envelop the section without restricting material flow; they must apply the pressure to the curve and prevent waviness (buckling) in the compressed area at the same time. The latter action is similar to the function of the hold-down ring used in deep drawing; therefore, the application of spring or hydraulic pressure would be logical, but is practically never applied. To reduce wear, the curving shoes are occasionally used in combination with curving rolls.

To prevent buckling of tubes during bending, flexible plugs are used. Similar plugs are used

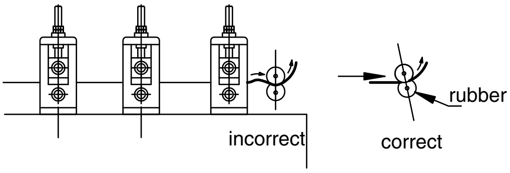


FIGURE 4.85 The location of the elastic roll is important.

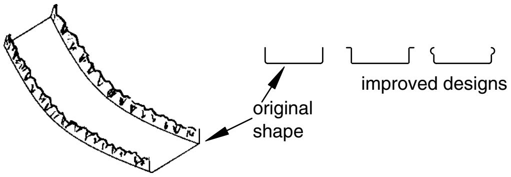


FIGURE 4.86 Stiffeners can reduce the buckling of inward forcing legs.

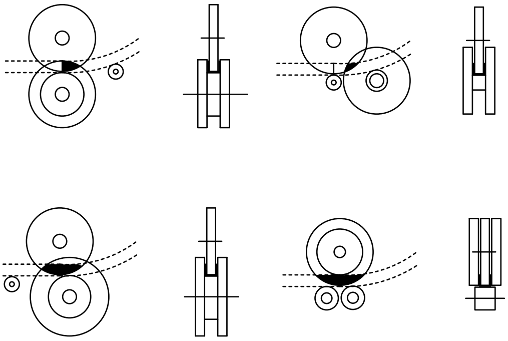


FIGURE 4.87 Containing the legs between the rolls (ironing) will reduce buckling.

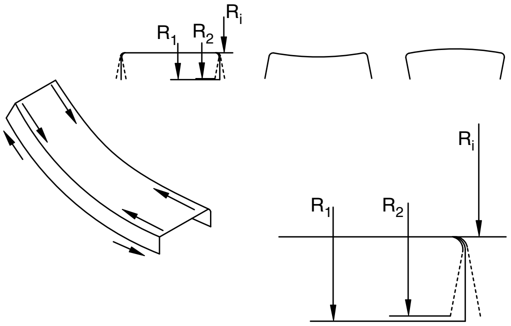
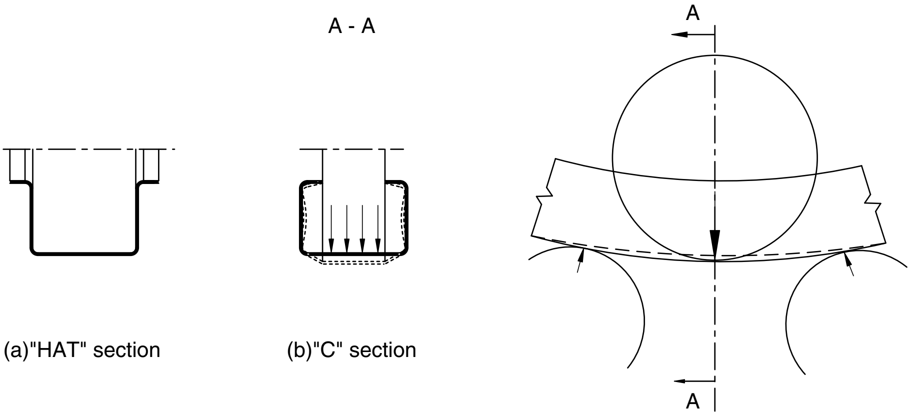


FIGURE 4.88 Legs facing out are under tension and can bend further in or out after exiting from the curving rolls.



(a)"HAT" section (b)"C" section

FIGURE 4.89 Product can be deformed during curving if curving tool cannot reach the bend lines.

during curving roll formed products, but the product slides between the inside plugs and outside shoes or rolls. Because the plugs are flexible, they do not curve the product, but in many cases, they are essential for preventing buckling. The plugs can be anchored at a fair distance from the curving equipment because the anchor must reach into the inside of the product where it is till open.

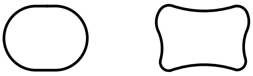


FIGURE 4.90 Closed, welded section may deform during curving.

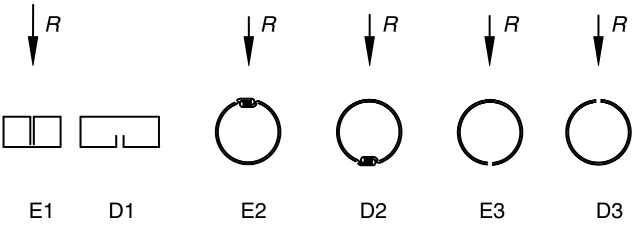


FIGURE 4.91 Difficulties vary from easy to difficult (E1, E2, E3, D1, D2, and D3) when curving nonwelded closed sections.

4.11.10 The Effect of Roll Forming on Curving

Roll forming mill induces stresses into the product. These residual stresses can distort the straight product and are compounded with the stresses created during curving. For example, in the case of a simple U channel, bend lines travel straight in the roll former, whereas the edges of the strip are traveling in a longer route. Therefore, the edges are stretched during roll

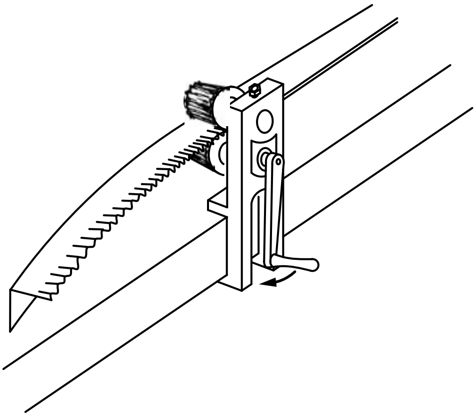


FIGURE 4.92 Regular prebuckling is more acceptable and helps curving.

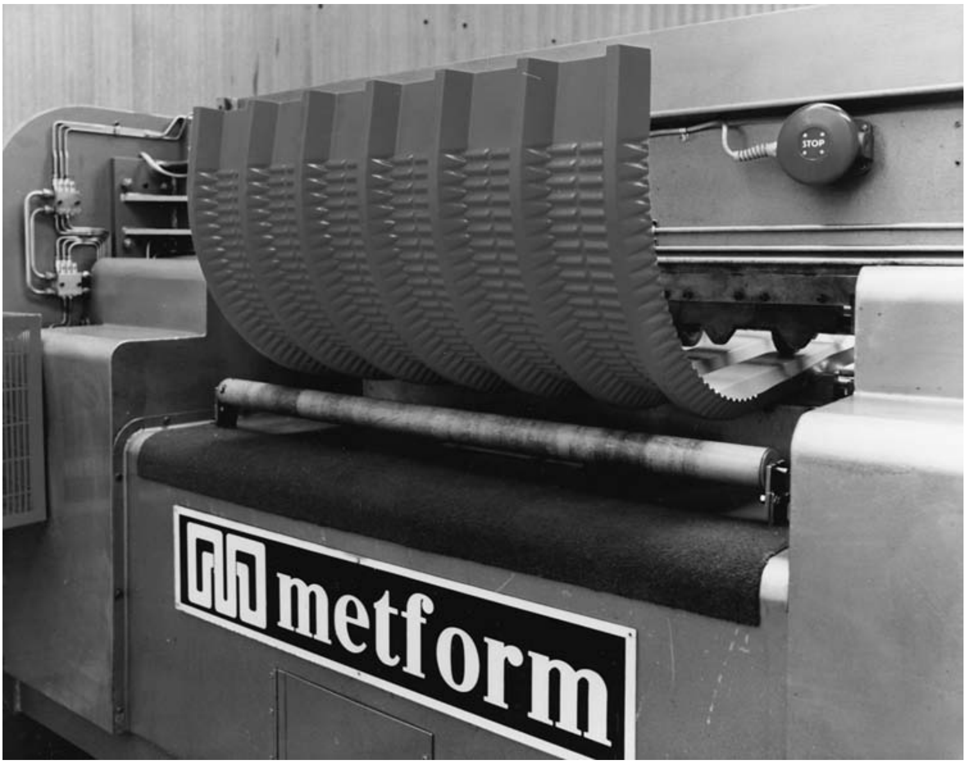


FIGURE 4.93 Building panels curved in press brake. (Courtesy of Metform International Ltd.)

forming, even if they are compressed back at the last pass. The channel will have the natural tendency of bending downwards as shown on Figure 4.97a. If the U channel is curved in the direction of the legs (legs in), then the already compressed legs will be exposed to additional compression (Figure 4.97b).

To avoid or at least minimize the above-mentioned effect, it is advantageous to pass the material through the roll former with rolls stretching the web and compressing the legs. Roll forming in this manner requires a special

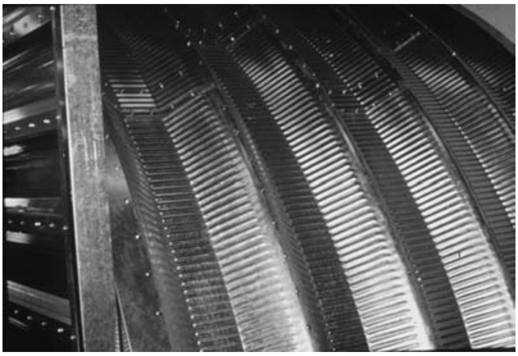


FIGURE 4.94 Arched building components are curved by forming indentations in the panels.

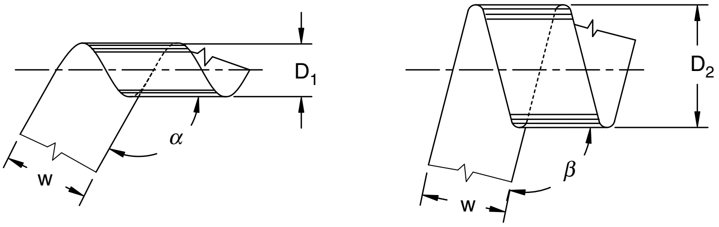


FIGURE 4.95 Different diameter spiral pipes can be made from the same coil width by changing the helix entry angle.

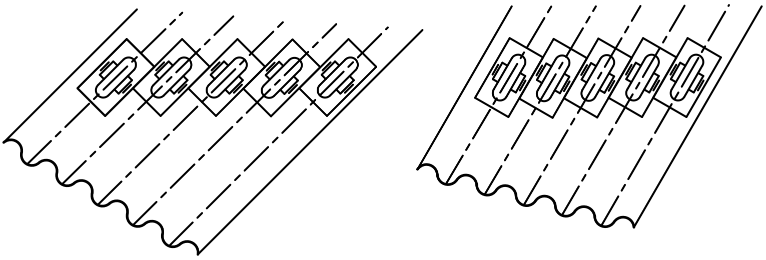


FIGURE 4.96 Spiral curving of culvert pipes can be made with the same tooling.

mill that can induce stresses to help to curve the U channel in the required direction (see Chapter 15). This method can be more useful when curving deep, light gauge channels, made out of high strength, low elongation materials, product typical of HSLA or UHSS automotive bumpers.

A similar approach can be followed with other products, inducing the correct stresses to curve or twist the product in the direction of the final curving or twisting. Unfortunately, there are not enough data or equations to accurately calculate the anticipated stresses. Therefore, designers usually shy away from these logical approaches.

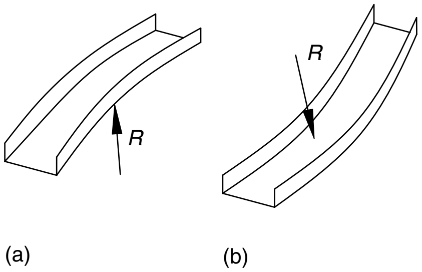


FIGURE 4.97 The legs stretched during roll forming contribute to bowing down of the finished product (a) that makes curving of the channel in the opposite direction (legs-in) more difficult.

4.11.11 Effects of Cutouts and Dimples

Roll forming is the most productive metal fabricating method; therefore, the trend is to incorporate as many other operations in the roll forming line as is economically feasible. The aim is to produce finished products at the end of the roll forming line. To achieve this goal, products with prepierced holes, notches, lances, dimples, louvers, or embossed holes are frequently required to roll form and curve. Most of these flat surface discontinuities will adversely effect curving. Stresses created by curving will not be uniform, affecting and sometimes varying the radius of the curved product.

Grooves have to be provided in the curving tool to avoid flattening of dimples, lances, or embossed holes. These protrusions should be located far enough from the bend corners to allow as wide as possible contact surface between curving tool and material [232].

Hole-to-hole distances in the outside fibers (away from the center of the curving radius) will be increased and the holes will be elongated during curving. The opposite effect will occur in the holes at the inner fiber.

Holes that are too close to the edge can create additional problems. The small material left between the holes and the strip edge will buckle when the material is compressed during curving and the hole will be deformed.

Cutouts have one additional bad effect on curving. The portion of the product weakened by notches or holes can easily buckle during curving (Figure 4.98), especially when curving is made by rolls. If the cutout is on one side only, then the cutout side will buckle more than the other one, adding a twist to the product. The problems with cutouts are usually less pronounced and it is easier to correct when curving is accomplished with shoes. Burrs left on cutouts, however, may create excessive wear on curving shoes.

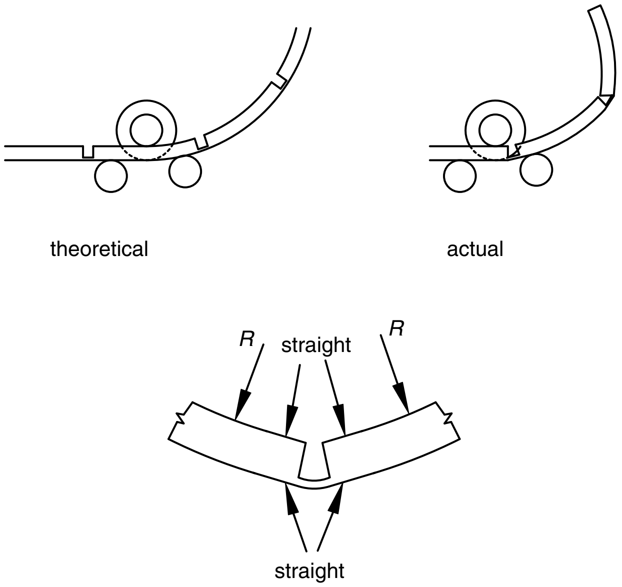


FIGURE 4.98 Change in product cross-section, such as notches and holes, usually causes buckle.

4.11.12 Alignment and Adjustments of Curving Tools

The roll forming mill and tooling must be well aligned to produce good-quality products with tight tolerances. Shaft shoulders, against which the rolls are positioned, should be aligned within 0.001 to 0.003 in. (0.025 to 0.075 mm) in the vertical direction and within 0.002 to 0.005 in. (0.05 to 0.125 mm) in the horizontal direction. The shoulder-alignment tolerance requirement depends on the product tolerance, surface quality requirements and material thickness. To check such tight tolerances, a straight edge and feeler gauges, or dial indicator, or laser (or optical) alignment methods are required. Similar accuracy is needed in every direction in the curving equipment. Unfortunately, at many plants, the additional units such as entry guides, side-roll stands, and straightening or curving units are not accurately keyed to the mill base, but aligned solely by eyesight. Misaligned curving units create additional stresses and problems, causing twist or a change in the radius. Therefore, it is important that the operator is able to finely adjust the curving dies in any direction. To ease setting and control, good, easily readable scales should be installed in the direction of each movement.

If the curving unit is used for more than one product formed at different pass heights, then in addition to the fine curvature adjustment, a quick height adjustment is required to suit the position of the products. In many cases, the best solution is to have interchangeable, separate curving units with dies for each cured section.

4.11.13 Controlling Radius and Curving to Variable Radii

The curving radius is affected by so many factors (some of them vary even within one coil) that additional tooling, equipment, and control devices are required to keep the radius within specified tolerances. Additional tooling such as supporting, pushing, twisting rolls, or shoes may be required to avoid postcurving deformations of sections being asymmetrical to the plane of curving.

Some asymmetrical shapes may require five to six additional rolls to the original three curving rolls. This multiple set of rolls can also assist to reduce flat (noncurved) lengths at notches and to keep bends at the correct angle.

For long, heavy products with large radii, a supporting roll or rolls may be required. Without support, the weight of the product will straighten out the tail end of the curved part (Figure 4.99).

Radius control arms, photocells, or proximity switches, which control curving rolls through servo mechanisms, can keep the radius within tight tolerances (see Figure 4.100).

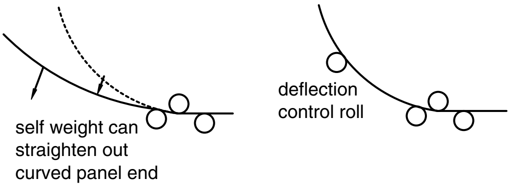


FIGURE 4.99 Long, heavy products require support during curving.

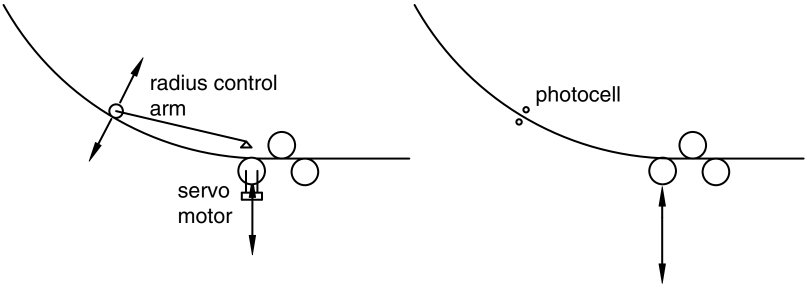


FIGURE 4.100 Curvature can be controlled by mechanical or electronic means.

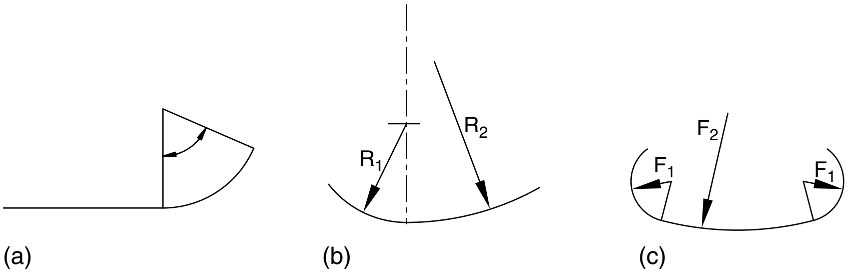


FIGURE 4.101 Mechanically or PLC or computer-controlled units can curve one end only (a), or curve to two radii (b) or to multiple radii (c) of a single product.

By applying length sensors or measuring units and controlling the curving roll position through servo mechanisms, or by using a programmable controller or computer, it is possible to produce partially curved parts. Components curved to two or more radii, or curved to variable radius (Figure 4.101a–c) can also be manufactured.

4.11.14 Cutting to Length after Curving

The cutting of continuously curved products can be classified in three groups, namely:

(1) Cutting a segment of a circle
(2) Cutting a full circle
(3) Cutting helically wounded tubes to length

Similar to straight roll formed sections, curved products can be cut by shearing through the full cross-sections or shearing a partial cross-section at prepierced or prenotched locations. The cutoff can be single or double shearing, and it may be combined with additional operations such as piercing holes, embossing, swaging, or bending.

The cutoff method can be shearing, saw cutting, or cutting with flame, laser, plasma jet, or other means. Product length can be sensed or measured with flag switch, photocell, proximity switch, positive stop, rotary encoder, or locating prepierced holes, notches, or other methods applied in conventional roll forming lines.

When the product is roll formed and curved at a relatively low speed, a fast-acting cutoff die travels tangentially to the product on straight rails only for a short distance; therefore it may not distort the section (Figure 4.102 and Figure 4.104).

Small curving radii, high production speeds, or slower presses frequently demand flying cutoff die traveling in a circular motion (Figure 4.103). In these cases, it is better to use a simple rotary flying press and die to cut products curved to different radii. In these rotary (swinging) cutoff presses, both the position of the center pivot pin and the length of arm are adjustable. In the case of lower production speeds, flying cutoff dies can be used, traveling on curved rails. However, separate curved rails are required for each radius.

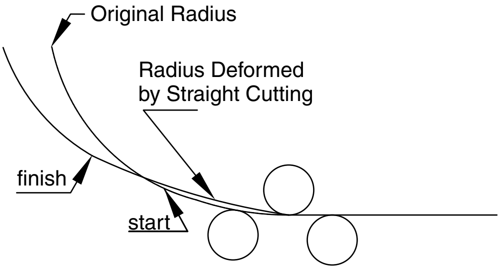


FIGURE 4.102 Short straight cutting-die travel may be used for cutting products curved to large radius.

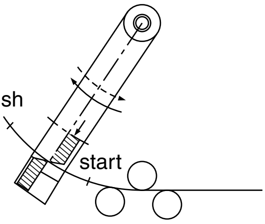


FIGURE 4.103 Cutoff press travels in an arc.

4.11.14.1 Cutting Segment of a Circle

Curved products manufactured in large quantities can usually be cut by positioning a conventional cutoff press in the proper position. When the product is curved in the vertical plane, the conventional press is tilted. Alternatively, unusual arrangements can be made such as tilting the entry end of the mill upwards.

When the curving is in the horizontal plane, the conventional press can be kept in the usual, vertical position, but moved and rotated sideways in the path of the curved product (Figure 4.104). To suit curvature in any plane, special adjustable press bases can be built.

4.11.14.2 Cutting Products Curved in about 360°

Special pneumatically or hydraulically operated rotating presses, which swing around a pivot point, are used to cut circular products (Figure 3.10). To minimize the danger of reentering the cut end into the curving die after a full circle, the product is usually deflected sideways by a buffer plate to create a spiral shape. The cutoff die is often positioned close to the curving tool. The product is guided (flexed) sideways in a spiral form. After one full circle, it enters the cut off die instead of entering again into the curving die. This deflection usually does not create permanent deformation and the ring springs back into the same plane.

Automotive brake dust rings and many other products are made in this way. After cutting to length, cut ends of bicycle rims are be joined by welding or by other methods. The full circle product then can be slightly stretched to the specified diameter and shaped to tighter tolerances.

4.11.14.3 Cutting Helically Wound Pipes to Length

The spiral forming is a practical method of producing pipes to infinite number of diameters using simple tooling. To avoid the necessity of making a cutoff die for each diameter and deforming the thin-wall tubes or pipes, many pipes are cut to length by flying saw, laser, or other similar cutting methods.

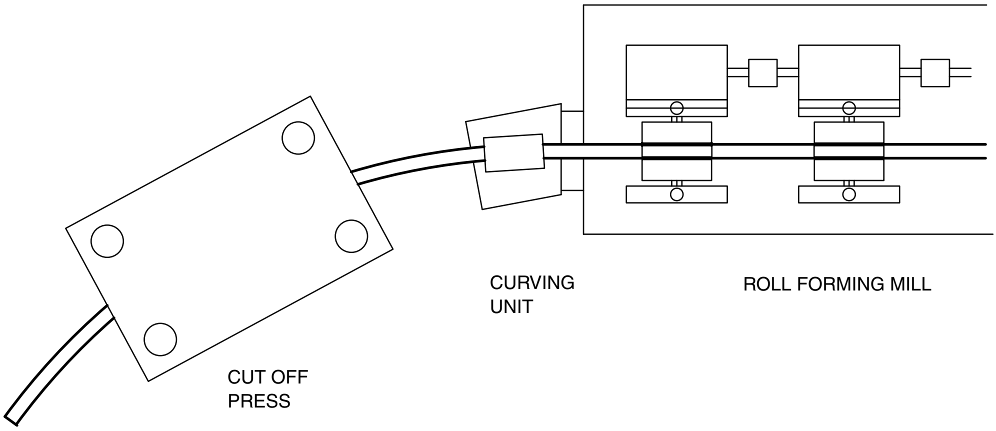


FIGURE 4.104 Presses having straight or curved die rails can be moved sideways to suit the path of the curved products.

The saw unit travels at the same speed as the pipes moving longitudinally, while the pipe also rotates. The saw blade enters the pipe at one point, and after one full rotation the pipe is cut through. Figure 4.106 shows a flying saw cutoff arrangement for culvert pipes.

4.11.15 Tool Material and Lubrication

Good curving rolls are made of at least the same quality tool steel as the forming rolls. They are to be machined, heat-treated, and polished in the same fashion as the forming rolls. Occasionally, curving rolls are plated to match the coating of forming rolls. Bronze rolls are used (albeit infrequently) to minimize scuffing and surface marks.

Curving shoes are occasionally made from hardened tool steel, manganese steel, or from tungsten carbide inserts. The most frequently used abrasion-resistant curving shoe material is the AMPCO bronze.

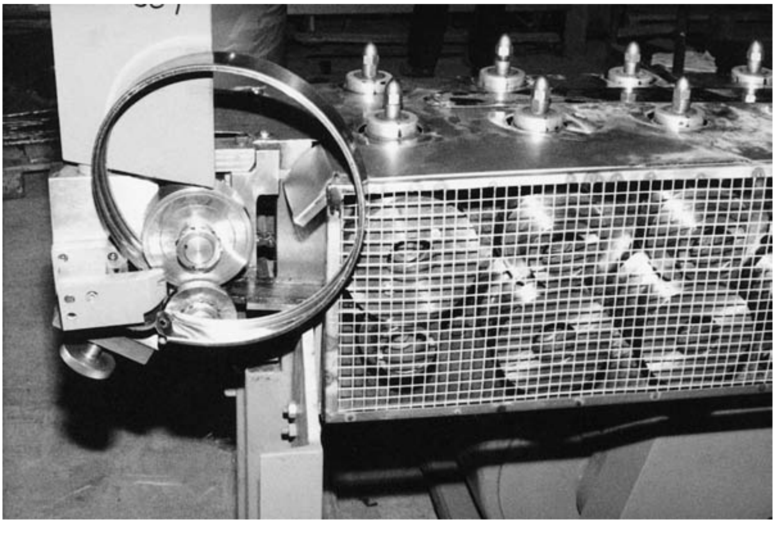


FIGURE 4.105 When the product is curved into a full circle, deflector plates prevent the cut end from reentering the curving tool.

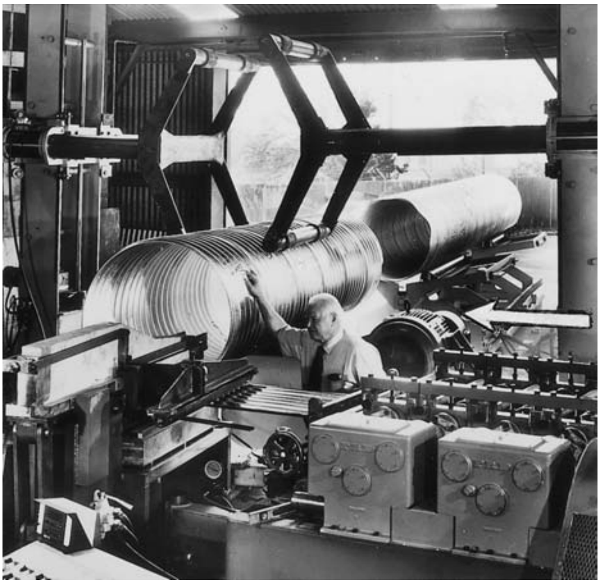


FIGURE 4.106 Flying saw cuts off culvert pipes. (Courtesy of Pacific Roller Dies. With permission.)

Aluminum bronze or other material can be used to curve aluminum. Wear-resistant plastic or other materials can also be used for curving shoes. However, burrs, sharp edges, notches, and holes can damage plastic shoes. For testing, sometimes well-lubricated hardwood blocks are sufficient.

Applying lubricant to the roll curving tool is as important as applying it to forming rolls. It is, however, still more important, even essential, to use lubricant when curving shoes are used.

Good lubricant, compatible with both the formed material and the curving rolls or shoes, will reduce tool wear, eliminate or minimize surface marks, and contribute to even curvature.

4.11.16 Curving by Reducing the Thickness of Material

The increased material thickness at the inside of the curved product and the decreased thickness of the outside section during curving have been mentioned in the early part of this section. Utilizing this thickness change, it is possible to curve a section only by reducing the thickness of the outer part of the cross-section before curving. The thin, reduced cross-section will be longer than the thick one. The ratio of the length change will be equal to the ratio of the thickness change. To equalize the stresses created by the differences in the length, the product will curve itself.

This procedure is applied, for example, in the manufacturing of auger (Archimedes) screws, in the transfer of granular material and liquid. This method is very seldom utilized in the curving of roll formed products, because roll forming mills are usually not designed to change material thickness. However, the procedure can be used if the mill has adequate strength. In some instances, such as curving U channels with leg in, mills have been designed with a last pass that has larger diameter shafts than the others. This last pass is used to reduce the thickness (thus elongate) the web of the U channel, inducing a curvature. Controlled thickness change (see Figure 4.107) induces the curvature automatically [232] but sizing rolls would still be required to assure constant radius.

The thickness reduction at the entry side of the roll former is more applicable to symmetrical than to asymmetrical sections, because only the waviness created by the length differential is to be considered during roll forming. In the case of asymmetrical section, camber introduced by the difference in edge length will create considerable roll forming problems.

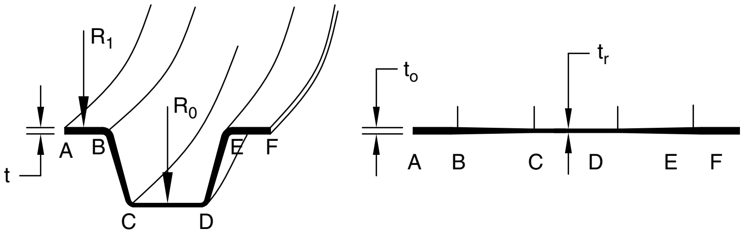


FIGURE 4.107 Curving can be achieved by reducing the thickness of the outer fibers.

4.12 Marking

Permanent product marking is frequently required. Stationary or flying dies can be used for permanent marking.

In thick materials, the marks are most often stamped in. The stamp either remains unchanged (trade mark, supplier's name, "Made in USA," etc.) or is variable for serial numbers or other identifications.

The marking is most frequently embossed in thin materials (see also Section 4.9).

Rotary die or ink stamping, ink jet, adhesive bonded tag, laser, and other marking methods are also used by the manufacturers of nonpermanent or permanent marking.

4.13 Swedging (Off Setting)

In the swedging operation, the shape of the cross-section is changed (Figure 4.108). Swedging is applied when product has to be overlapped with the same surfaces remaining at the same height. Swedging is usually carried out in the cutoff die and requires considerably higher tonnage than simply shearing the same product.

4.14 Rotary Dies

4.14.1 Rotary Dies and Stands

The roll forming industry has developed a unique rotating die concept, utilizing the continuous travel of the strip propelled by the roll forming mill. In the rotary die, the top and bottom rolls are geared together (Figure 4.109). One roll holds the punches, the other one holds the dies. The rotary die is usually driven by the strip through friction or by punch engagement. If a slug is generated, then the bottom rotary die usually has a cavity, with one or both ends open for slug disposal.

Rotary dies can be used for punching, notching, partial punching, dimpling, piercing, embossing, limited flanging, louvering, mitering, slitting, coining, marking, serrating, knurl ing, shearing to length, curving, and other operations.

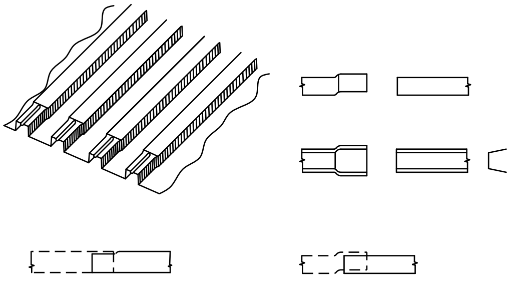

(a) same plane (b) not in the same plane

FIGURE 4.108 Cut ends are swaged when overlapping product surfaces must remain in the same plane.

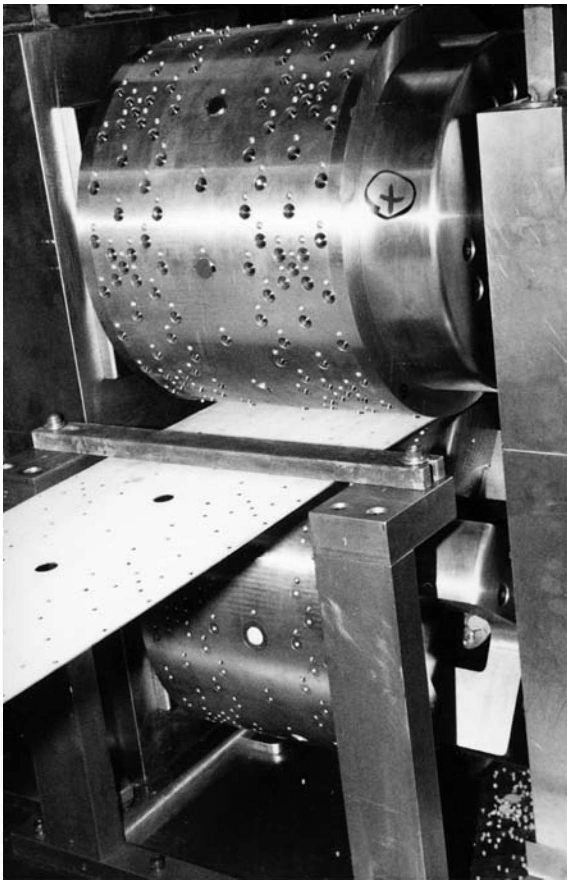


FIGURE 4.109 Rotary punching unit. (Courtesy of Delta Engineering Inc.)

The advantages of the rotary dies are:

- Less expensive than press and dies.
- No feeder (or die accelerator) is required.
- Usually no drive is required.
- Speed is not limited (can run at 1000 ft/min [300 m/min]).
- Provide uniform repeated pattern.

The disadvantages are:

- Less flexible than the conventional press method.
- The pattern is uniform, but it is difficult to make adjustments.
- Material thickness for punching is usually limited to 0.070 in. (1.8 mm). However, with special arrangements, thicker materials (e.g., 0.200 in. [5 mm]), can be processed.
- Burr may be heavier than those generated by conventional punching, but frequently the burr is flattened by the rolls used for forming.

In most cases, rotary punches, notching tools, and dies require precise locating; hence, backlash gears are used on both rolls. However, if a series of less critical holes are required in the longitudinal direction, such as nail holes for sidings, then the rotary operation can be simplified. The upper die has the punches and the lower roll has only a slot (Figure 4.110a). The punches cut through the material and push the slugs into the slot. Close to the bottom, a finger reaches into the slot, prying the slugs out from the slot (Figure 4.110b). This small, relatively low-cost arrangement does not require backlash gearing between the top and bottom rolls. The burr will be larger after punching, but the rolls in the mill will flatten the burr down.

Rotary operations are frequently similar to the press operations. The forces generated by the operations are larger then the ones required for forming. Therefore, rotary operations usually require larger shaft diameters, larger capacity bearings, better top shaft adjustment, sturdier stands, and very accurate shoulder alignment.

If the distance of the holes, notches, embossment, and louvers from the strip edge is critical, then the strip can be trapped in the rolls (Figure 4.111). In other cases, such as decorative embossment, the rolls are wider than the strip and the use of strip entry guides are usually sufficient.

During the rotary operations, the tool is engaged in the material. As a result, there is no material slippage during engagement and no compensation for strip speed differential between the rotary and roll forming operation. The simplest solution to avoid problems is not to drive the rotary tools.

The material must be engaged into several passes to have sufficient friction to pull through the rotary dies. It is feasible to open up the gap between the rotary dies, engage the strip into the mill and then close the gap again. This is a time-consuming process and the lead end of each coil would be wasted. Therefore, in the case of small forces (thin material, single hole, or embossment), the operator side of one shaft can have a square end to facilitate a hand crank (Figure 4.112). The strip is moved through and punched (embossed) between the rolls by hand until sufficient length is generated to be caught and pulled by the forming rolls.

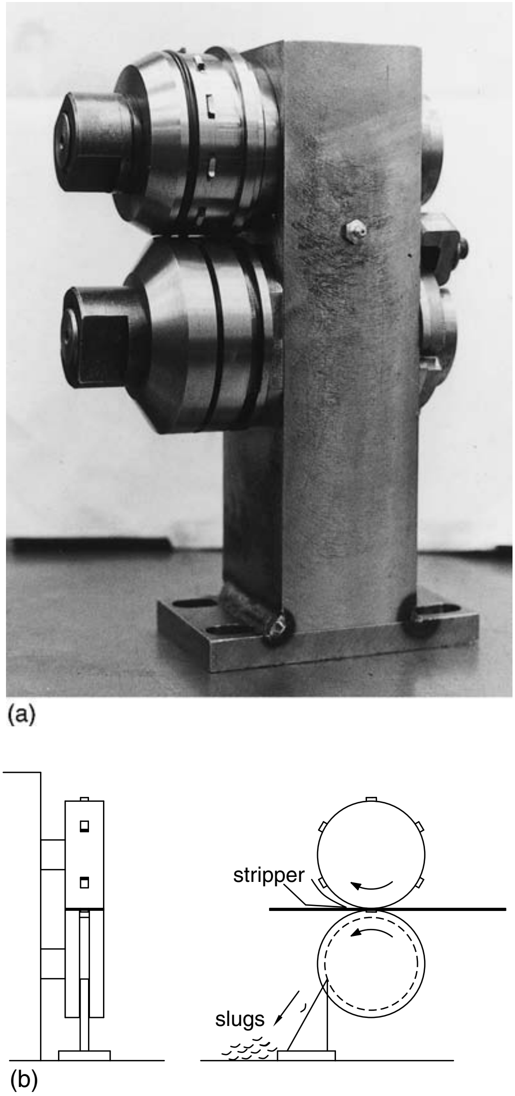


FIGURE 4.110 Rotary punching unit utilizing punches in the upper roll and a slot in the bottom roll (a); slugs are removed with a finger reaching into the slot (b).

Manual threading is neither practical nor feasible when the torque requirement is too high (thick, high-strength material, multiple operations at the same time, etc.). In these cases, a motorized, slow die rotation is used with an overriding clutch. The strip passes through the rotary dies slowly, and once the forming rolls grab it, probably at the third or fifth pass, it is pulled through by the mill at a speed higher than the speed of the rotary tool roll. Then, the overriding clutch lets the strip turn the rotary unit. An alternative solution is to weld the coil ends together.

If the rotary operation was not considered at the time of designing the line, and the mill does not have sufficient horsepower motor to pull the material through the rotary dies, then a separate rotary punch drive may be required. Because it is very difficult to synchronize the speed of the mill and the rotary operation, a loop with a loop control is recommended between the rotary unit and the mill.

4.14.2 Rotary Punching

In rotary punching, the conventional up and down movement of the press ram is replaced by rotating tools and dies. One of the rolls, usually the upper one, contains the punches and the other one the dies. The two rolls are rotating with the same surface speed as the strip travels between them. The punch enters into the material at an angle (Figure 4.113), punches it through, and then gradually retracts from the hole as the rolls rotate and the strip moves. The angle between the punch and the strip changes constantly during this process.

It is well known that geared teeth profiles have an involute curve shape. This shape enables smooth entry and exit of the teeth.

The rotating punches and the dies cannot have involute shape; therefore, there is always a degree of interference and deviation from ideal conditions. The smaller the roll diameter is in relation to the material thickness, the bigger the interference and the problems created by this interference.

To minimize the problems created by this deviation from the ideal conditions, the ratio of the roll diameter to the material thickness must be kept relatively large. Practical experience indicates that the roll diameter should be at least 250 to 270 or even 300 times the mild steel thickness ($D = 250$ to 270 t). In the case of slotted bottom die, the ratio can be smaller ($D = 170$ to 180 t).

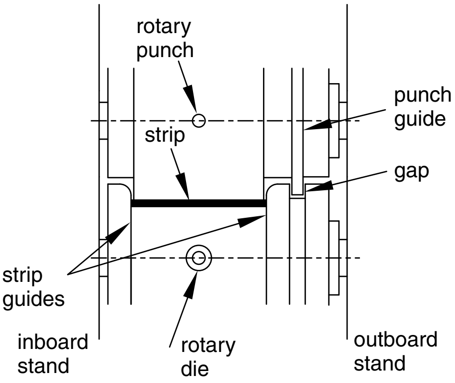


FIGURE 4.111 Strip trapped between rolls during rotary punching.

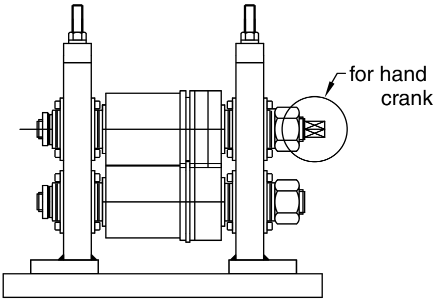


FIGURE 4.112 The entry end of thin strips can be hand-cranked through the rotary punches.

The exact roll diameter is a function of the distance between the holes in the finished product. For example, if the material thickness is 0.024 in. (0.61 mm), then the approximate diameter of the rolls should be about 250 × 0.024 = 6 in. (152.4 mm). If the hole distance in the finished product is 3 in. (76.2 mm),

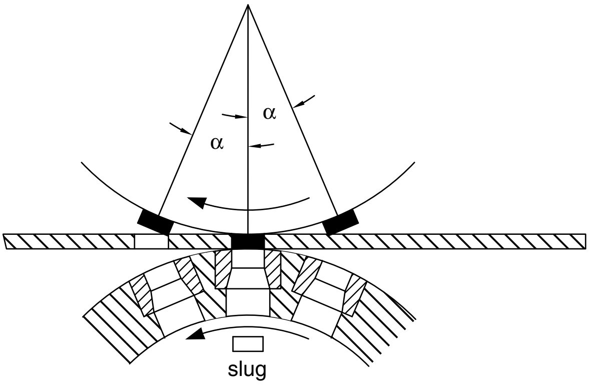


FIGURE 4.113 The angle between the punch and the strip continuously changes during the punching process.

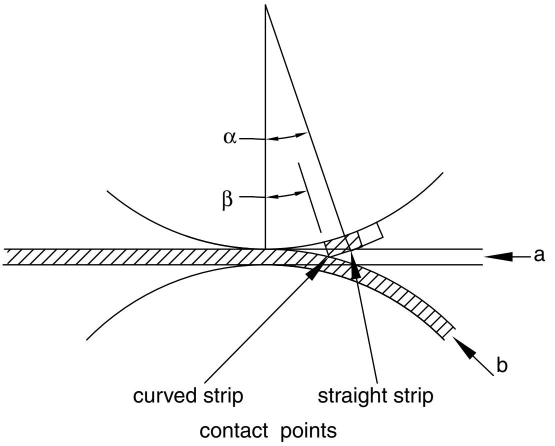


FIGURE 4.114 The punch enters at a smaller angle (β) when the strip is wrapped around the die roll (b), compared with the usual tangential entry (a and α).

then the perimeter of the rolls should be 18 in. (457.2 mm) for six punches and dies. The approximate roll diameter, therefore, will be 18 ($\pi = 5.73$ in. (145.5 mm) for six punches and dies, or 6.68 in. (169.8 mm) for seven punches and dies around the perimeter.

Figure 4.114 shows that if the incoming strip is wrapped around the die roll, then the punch enters into the material somewhat later than in the case of a straight entry. This approach provides slightly better accuracy than in the tangential approach. With reasonably good accuracy, the roll diameter plus two times the material thickness can be used to calculate the driving perimeter (Figure 4.115). Because of the angular motion, even this approach requires some correction. Rotary die manufacturers are using their own equation to calculate the proper roll diameters.

In every case, however, it is important to keep the punches as short as possible. No extra length should be allowed for regrinding. When regrinding is required, a shim, equivalent to the amount of grinding, has to be placed underneath each punch. For example, if the punch length is reduced by 0.003 in. (0.076 mm), then a 0.003-in. (0.076-mm) shim should be placed underneath of each punch.

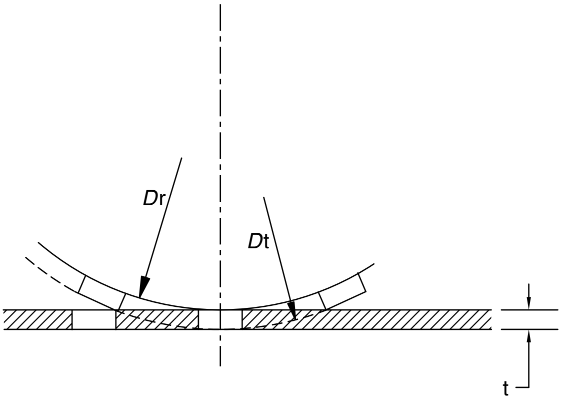


FIGURE 4.115 The actual driving diameter is close to D_t.

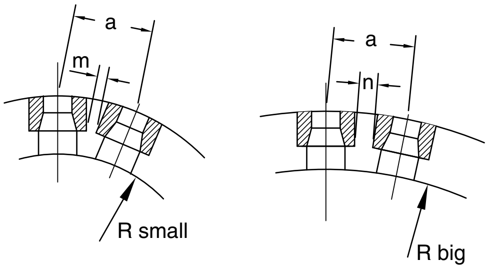


FIGURE 4.116 The die roll wall must have sufficient strength. If "n" is too weak, increasing the roll diameter sometimes helps ("m" is sufficient).

To prevent the slugs from falling onto the strip, the upper roll contains the punches and the bottom roll contains the dies. The slugs fall into a cavity in the bottom die. It is advisable that the cavity is tapered to ensure that the slugs will fall out unaided from the rotating roll. The strength of the bottom roll wall should be sufficient to withstand the punching pressure as well as to provide enough distance between adjacent dies (Figure 4.116). If the distance between dies is too small, then increasing the roll diameter sometimes helps.

In special cases, instead of falling through the die opening, the slugs are knocked out with a special device. Similarly, the punch can be moved out of the home position with a cam at the last moment and then pulled back (stripped) to avoid the problems related to the angular entry and exit of rigid punches.

Because the punch normally exits from the hole at an angle, the stripping is more critical. The most common stripper is a smaller roll close to the roll containing the punches. An alternative is to have fingers reaching as close as possible to the contact point between the rolls. Proper tension on the strip and a well-placed stripper will provide a smooth, punched strip surface.

Rotary punching will create more burrs than ordinary punching; however, in most cases, the burr is flattened back by the pressure of the rolls in the roll forming mill. If burr cannot be eliminated in this way and has to face upwards, then different threading of the material can place the burr on the upper surface (Figure 4.117).

If punches are constantly engaged, then there is little chance for the strip to slip between the rolls. However, if the punches are far apart (e.g., only one or two punches are in the rotary die), then slippage may occur. A change in material thickness (from coil to coil, or within one coil) can also create slippage if the gap is set by screws. Slippage problem in these cases can be minimized by:

1. Using urethane, rubber, or other elastic material rings with an outside diameter slightly larger that the roll diameter of the rotary die.
2. Applying hydraulic or spring pressure instead of fixed position screw pressure.
3. Threading the strip around both rolls (Figure 4.117b) instead of contacting them at one line. The arrangement on the left side (Figure 4.117a) is used if the burr must face upward.

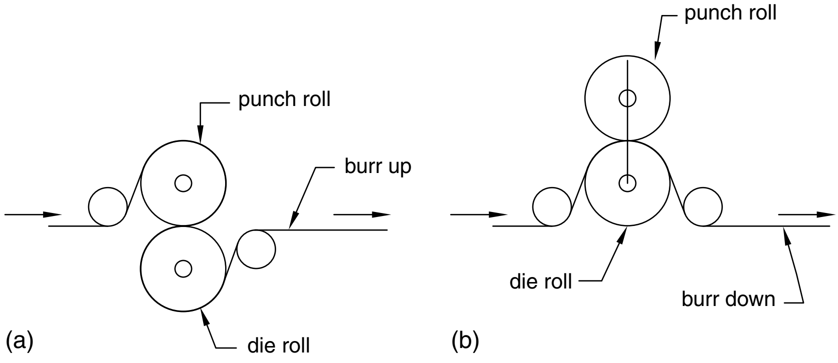


FIGURE 4.117 Threading the strip as shown in (a) reverses the burr direction; threading as shown in (b) reduces slippage.

Accurate alignment of the punches and the dies is very critical in rotary dies because of the rotary motion. To keep the punches and the dies angularly aligned, no-backlash gears are attached to the rotary die rolls (instead of just keyed to the shaft). In the direction of the shaft axis, the punches and the dies can be aligned with the male die reaching into a groove (Figure 4.118). The gap between the male and the female die should be only 0.001 to 0.002 in. (0.025 to 0.050 mm), and they should not touch each other. The gap is strictly for setup purposes; therefore, the shoulder alignment and shaft straightness are critical.

The biggest forces on the rotary die and the biggest resistance against pulling are during punching engagement. To minimize the shock, the sudden increase in pressure and the resistance to rotation, it is recommended to stagger the holes in the longitudinal direction wherever possible. An 80% reduction in the sudden increase of resistance could be achieved with a five-punch arrangement shown in Figure 4.119. A 66% reduction was achieved by staggering dimpling punches and dies shown in Figure 4.120.

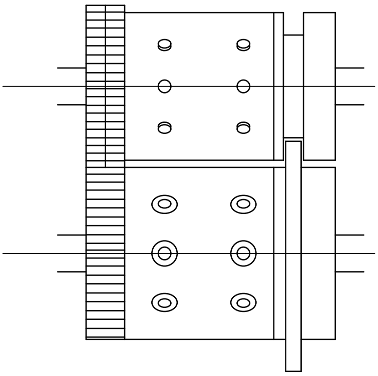
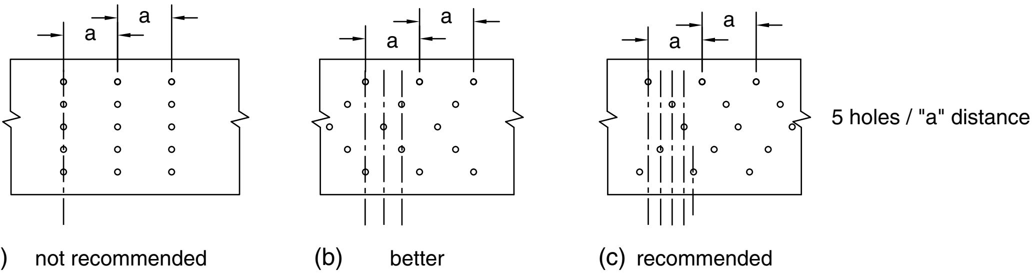


FIGURE 4.118 Punches and dies are aligned by no-blacklash gears and guide rolls.



(a) not recommended (b) better (c) recommended

FIGURE 4.119 Staggered punches reduce sudden loads by 80%.

Owing to the bending forces on the punches during entering and exiting, rotary punching is not recommended for small-diameter holes or narrow slots going across the strip. However, narrow slots in the longitudinal direction might be considered (Figure 4.121).

The surfaces of the punches are either flat (Figure 4.122a) or have a radius concentric to the roll (Figure 4.122b). Some punches are ground to different shapes to minimize pressure or to help slug disposal (Figure 4.122c). However, increasing the punch length may create other problems as mentioned before.

Rotary punches usually have a surprisingly long life. Occasionally, punches may break, usually as a result of misalignment. Therefore, a quick-punch-replacement design is essential. Removing the rotary unit, taking it apart, and putting it back together again would be a slow process. Punch removal is also required when shims are placed underneath the punches for regrinding. Proper fastening must prevent the slipping of punches and dies out of the rolls.

To ensure that the punches enter in the dies perpendicularly, it is recommended to tie the top shaft adjusting screws on the operator side and the drive side together. This will ensure parallel movements of the shafts, rolls, and punches.

As with other punching operations, lubrication can be a critical factor for tool life. The lubricant used for roll forming is not necessarily the best lubricant for punching.

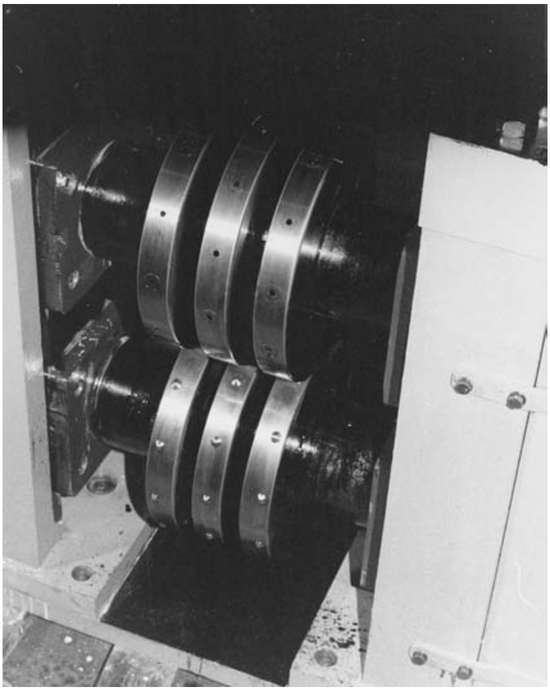


FIGURE 4.120 Staggered dimpling punches and dies reduce the load by 66%.

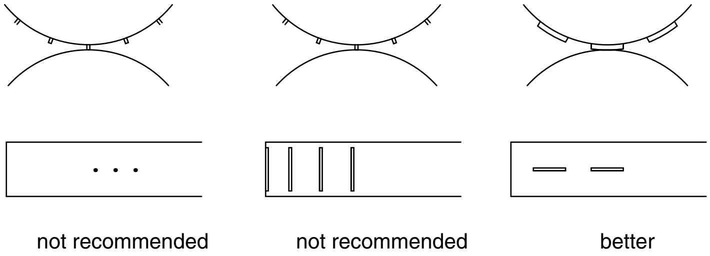


FIGURE 4.121 Small, slender punches can brake easily.

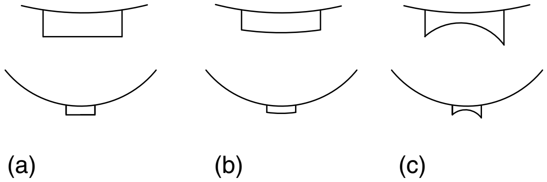


FIGURE 4.122 Punch surfaces can be different to reduce load or burr.

Owing to the high-speed operation, a very large number of slugs is generated. Mechanized removal of slugs (chute or belt) is recommended instead of frequent stopping of the line to remove the slugs manually.

4.14.3 Embossing

Rotary embossing punches and dies are similar to the ones used in the conventional embossing operations. The maximum depth of embossment is a function of factors described in Section 4.9.1.

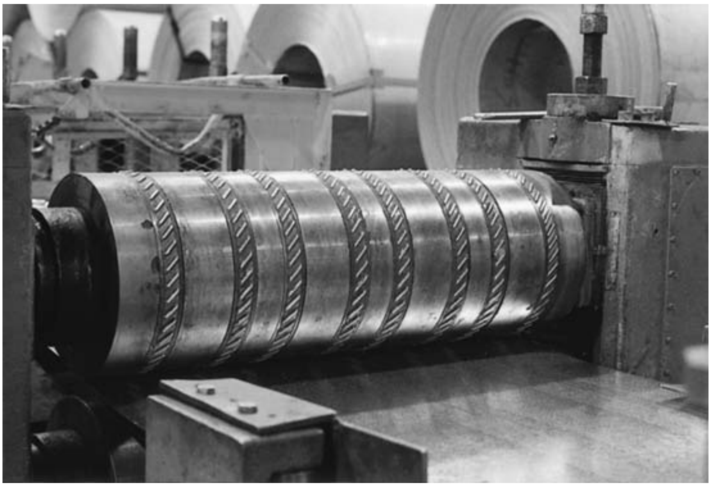


FIGURE 4.123 Rotary embosser for composite decks.

Because of the relatively large forces created by embossing, the rotary punches and dies are installed into a separate, usually undriven stand (Figure 4.123).

Usually, the shape and radii of the dies will eliminate the entering and exiting problems frequently experienced during rotary punching. However, in conventional dies, the material is kept flat by the die, while in rotary embossing, the contact is only at one line. This may create bigger distortion in the strip because the close, relatively deep embossments generate internal stresses in the material. Internal stresses may result in substantial bow. However, the longitudinal bow, occasionally accompanied with twist, can usually be disregarded because, in most cases, the product will be straightened by the stripper located at the exit side of the embossing rolls, by the bend lines, or by a straightener at the end of the line.

Too many deep embossments will reduce the length of the embossed section of the product. If the embossment is in the wide center part of a flat section with formed edges, then the products may twist or distort to such a degree that flattener cannot correct the problem.

If longitudinal embossments are at an angle to the direction of forming, then the rotary action may generate unwanted forces, thus pushing the strip sideways (Figure 4.124a). To minimize the problem and to reduce the camber and twist created by uneven stretching of the material to one side, symmetrically opposite embossment is recommended (Figure 4.124b).

Shallow embossments are used for identification (stamping) or for decorative purposes.

Decorative panels are embossed between special engraved rolls, which generate large forces and are usually installed on a separate stand with their own drive, with a loop before and one after the unit.

4.14.4 Louvering and Lancing

During louvering, lancing, and similar operations (Figure 4.43 and Figure 4.44), an opening is cut, adjacent to the embossed and or bent material, without creating slugs. Rotary louvering usually requires a considerably higher ratio of roll diameter to die penetration than rotary punching. Rotary louvering is successfully used

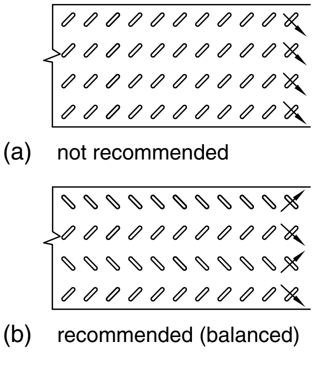


FIGURE 4.124 Modified embossing pattern (b) can eliminate the side pressure caused by embossments in one angular direction (a).

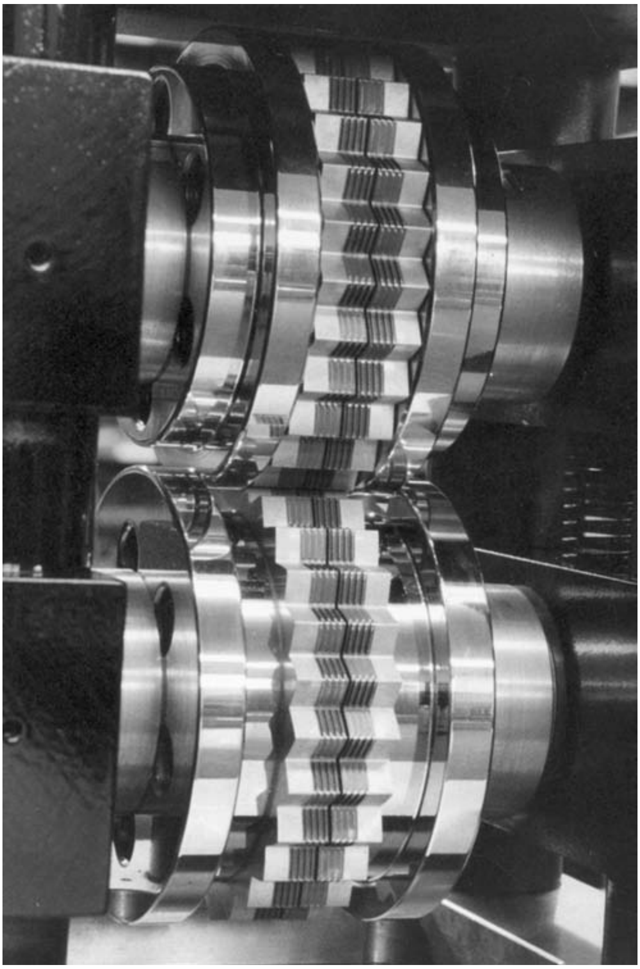


FIGURE 4.125 Rotary louvered heat exchanger strip. (Courtesy of Livernois Engineering Company, Heat Exchange Division.)

in many applications. For example, in the case of heat exchangers, 0.002 to 0.003-in. (0.05 to 0.075-mm) thick aluminum strips are rotary louvered at over 1000 ft/min (300 m/min) speed (Figure 4.125).

4.14.5 Grooving, Coining, and Knurling

In the process of grooving (Figure 4.126) and coining (Figure 4.127), the material thickness is locally reduced. In most cases, the roller opposite to the grooving and coining rolls have smooth surface.

In the case of knurling, both rolls have patterns. Given the proximity of peaks and the geometry of the pattern, this operation is a combination of embossing and coining. If the knurling pattern is not symmetrical, then one edge of the strip may become shorter than the other one. This can result in excessive camber, waviness, twist, and bow.

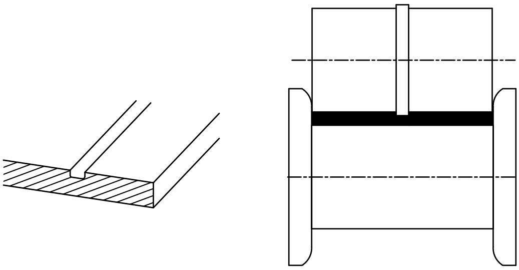


FIGURE 4.126 Rotary grooving.

In all three cases, the cold forming forces are substantially larger than the bending forces. Therefore, the shaft diameter should be checked for deflection and the stand for bearing capacity. Because of the die engagement and pressure, the strip is not slipping; therefore, coining and knurling rolls are usually not driven but rotated by the pulled-through strip.

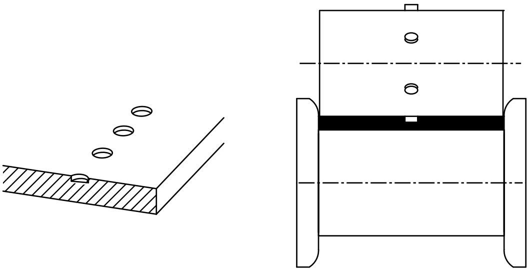


FIGURE 4.127 Rotary coining.

4.14.6 Slitting and Expanding

Slitting the strip in the roll forming line is usually applied to improve productivity or to produce different products, such as left- and a right-hand parts made from one common strip. The location of the slitting (ahead, in-between, or occasionally after roll forming) is determined by the circumstances. The two slit strands generally have to be moved sideways to accommodate rolls, straighteners, or cutoff dies. A sufficiently long distance must be allowed between the slitting knives and the first forming rolls for the traverse movement of the strands to avoid stretching of the slit edges.

Noncontinuous slitting is used when part of the product is to be expanded (Figure 4.128). Traverse stretching can be achieved by rollers or guides, but the nonslit, continuous part of the section will limit the amount of lateral movement.

Slitting requires more force than bending; therefore, the shafts used for this operation may have be larger in diameter than the rest of the shafts in the roll forming mill.

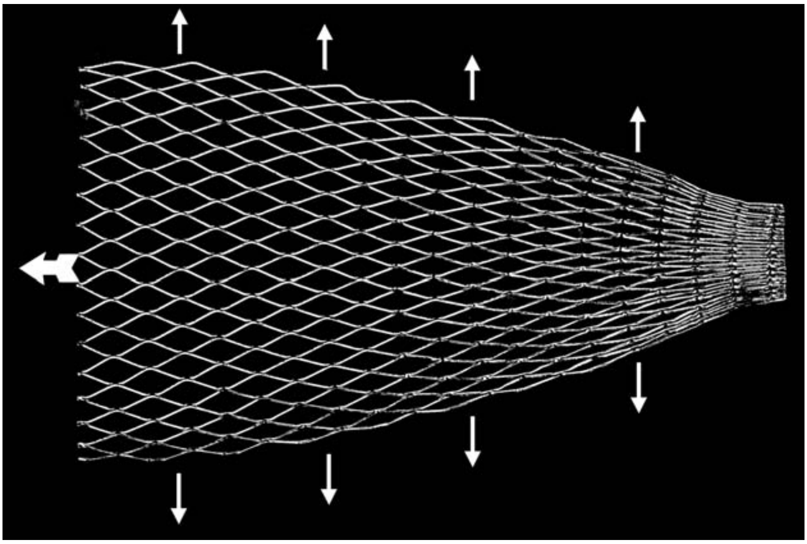


FIGURE 4.128 Expanded metal.

4.15 Mechanical Joining of Different Strips or Parts

4.15.1 Lock Seam

Lock seam is one of the oldest and least expensive methods of joining sheets. Lock seams at the edges of roll formed sheets are occasionally used to make wider panels. The most frequent application of lock seam is to join the edges of a strip to form a tube.

Figure 4.129 shows different lock seam designs. Figure 4.130 shows methods of improving the joint strength of lock seams by local impressions or serration. Figure 4.131 shows a lock seamed downpipe and a metal fence runner.

4.15.2 Pinching

Different metal, rubber, plastic, or other products can be mechanically joined to metal strip by inserting them into a groove and closing the groove opening with rolls. Figure 4.132 shows an automotive part, and Figure 4.133 shows an air duct joint.

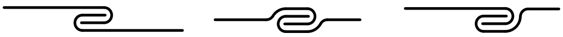


FIGURE 4.129 Different lock seams.

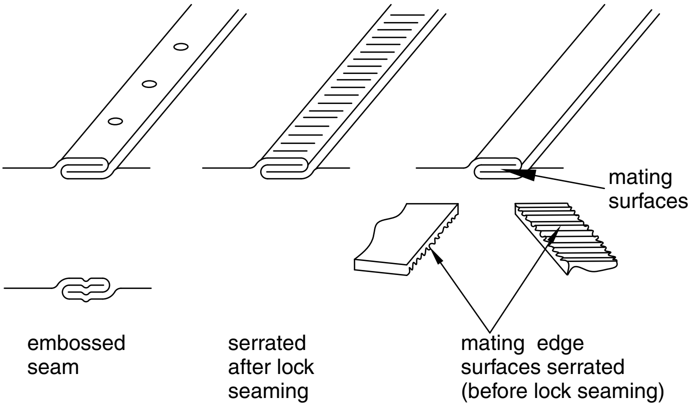


FIGURE 4.130 Serration increases the strength of the lock seam.

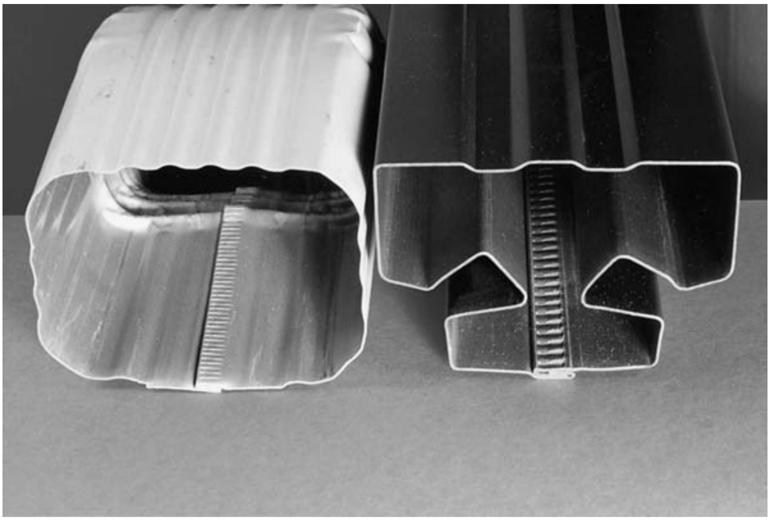


FIGURE 4.131 Lock seamed downpipe and metal fence runner.

4.15.3 Lancing

Sharp protrusions formed at the strip edge can be used to mechanically hold plastic or rubber extrusions. In one application, lancing is created by a rotary die. The extruded plastic, decoiled from a large drum, is pushed against the edge of the metal strip at the end of the roll forming mill. The lances pierce through the plastic extrusion, and are then bent down by rolls to hold the extrusion firmly as shown in Figure 4.44c (see also Section 4.8.3).

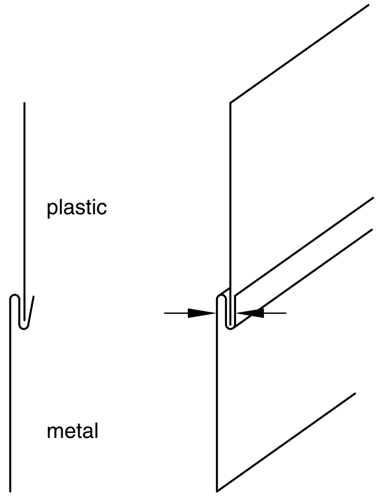


FIGURE 4.132 Metal–plastic joint (automotive part).

4.15.4 Roll Forming

Two different materials roll formed in two mills can be joined at a certain pass and then jointly formed to make the finished product. Figure 4.134a shows a typical ceiling tile supporting "T" rail and Figure 4.134b, automotive trims. Figure 4.135 shows a steel wire inserted into a roll formed ventilation product, serving as hinges. Figure 4.136 shows thick metal strips encapsulated in light gage strips to improve the mechanical properties of the product. Figure 4.137 shows a typical metal channel–plastic roller assembly used in conveyors. The holes are prepierced; the "C" channel is formed up to an angle that still allows the automatic insertion of the plastic rolls. After insertion, the two legs of the channel are closed to hold the plastic rolls in position.

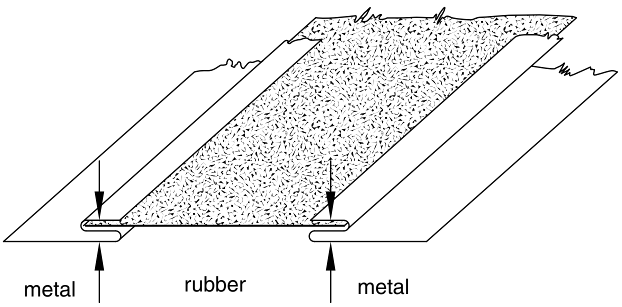


FIGURE 4.133 Metal–rubber joints (HVAC product).

4.15.5 Snap-In

The springiness of materials can be used to assemble roll formed sections with plastic or other materials. Joining two or more components in the line reduces assembly cost.

4.15.6 Stapling

Stapling is possible, but it is not a frequently used to attach other materials to the roll formed sections in the line.

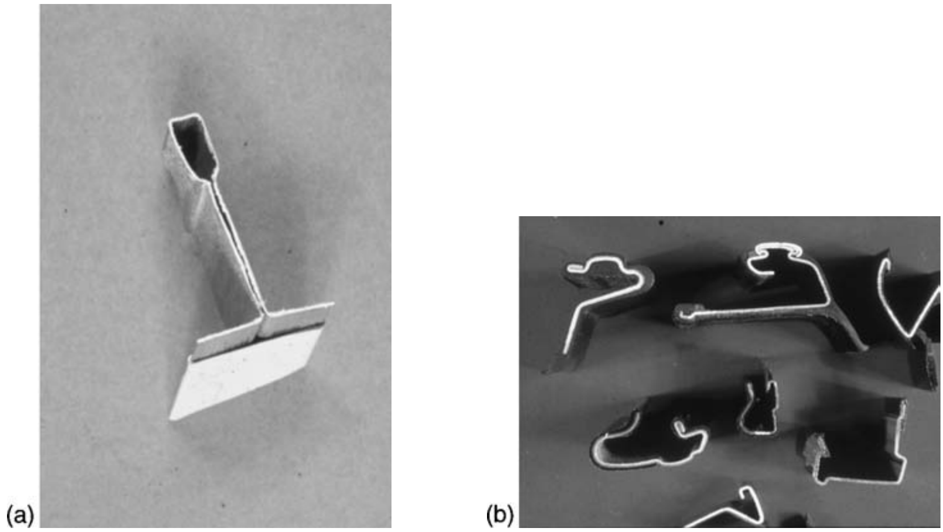


FIGURE 4.134 Different metals joined mechanically: (a) ceiling tile support "T" rail; (b) automotive trim.

4.15.7 Clinching

Two similar or dissimilar metals can be joined together by clinching. Clinching is somewhere in between partial punching and stitching. Double thickness of material is partially punched and then squashed back. After completing the operation, a visible but small amount of permanent deformation will remain at the point of clinching.

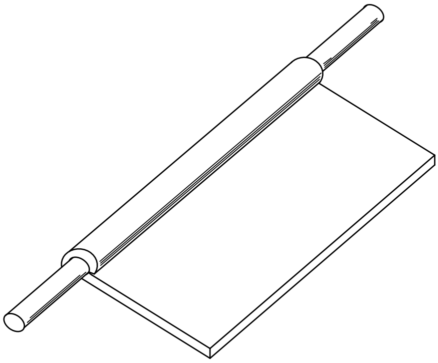


FIGURE 4.135 Steel wire inserted in a louver blade.

4.15.8 Riveting

Riveting is a well-known and conventional operation which can be applied to roll formed products. Automated feeders, self-piercing rivets and other improvements can speed up the

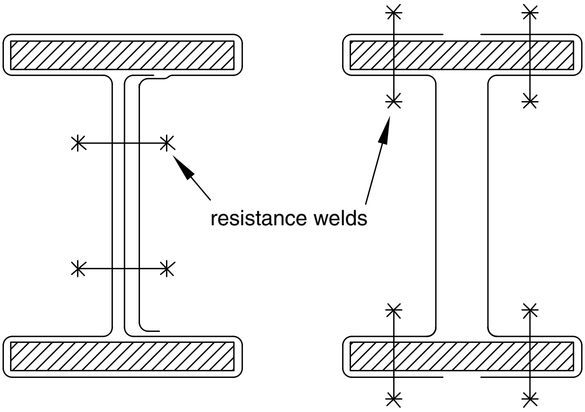


FIGURE 4.136 Inserted metal strips greatly increase the section modulus.

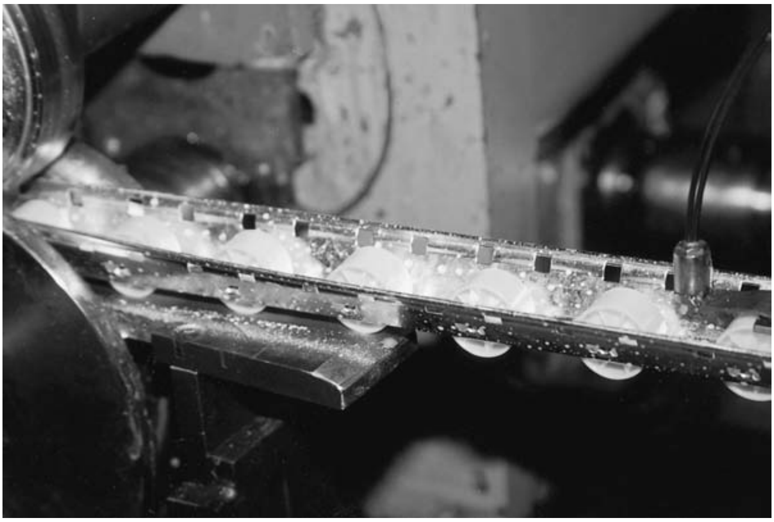


FIGURE 4.137 Automatically inserted plastic rolls are enclosed into the conveyor channel in the roll forming line.

assembly operations. Rivets can also be used to attach smaller items as well as plastics and other materials to the roll formed products.

4.16 Adhesive Bonding

Adhesive bonding of two metals is rarely used in the roll forming lines. However, adhesive bonding of other materials such as wood or plastics is often utilized in the assembly line of residential doors and other products. Adhesive bonding is also used to attach rigid foams or paper honeycombs to metal skins in the fabrication of sandwich panels.

In every adhesive bonding process, the surfaces to be joined must be clean. The usual lubricants applied by the mills or during the roll forming process may have detrimental effects on the bonding strength. To minimize lubrication problems, some companies use preprimed material without lubrication; while others apply evaporating lubricant during roll forming. Selecting the proper adhesive that is compatible with the bonded surfaces and thorough training of the operators is very critical factors to manufacture good-quality bonded products.

4.17 Soldering and Brazing

The usual soldering and brazing technology can be used in the roll forming line to join a flat part of similar or dissimilar materials, or a flat part to the edges of other materials (such as the metal honeycomb core of a sandwich panel). Another application is to provide watertight joins at the lock seam tubes. In this application, either the soldering/brazing material is already metallurgically attached to the edge of the strip or is fed into the hook in a wire form before the lock seamed edges are joined together. The lock seamed tube can be heated in the line to melt the soldering/brazing material to provide the water tightness as well as the joint strength.

4.18 Resistance Welding

Any of the conventional resistance welding process can be incorporated in the roll forming lines.

4.18.1 Spot Welding

In most cases, individual or multiple spot welding is used to weld stationary products after the forming and cutting process. Welding can be made with two opposing tips (Figure 4.138) or with one tip at one side and a large flat surface at the other side (Figure 4.139). Multiple welding can be made simultaneously but most frequently in a cascade mode, with guns fired in a sequence. The manual pincer-type welders are also used, but recently, they have frequently been replaced with robotic welding arms.

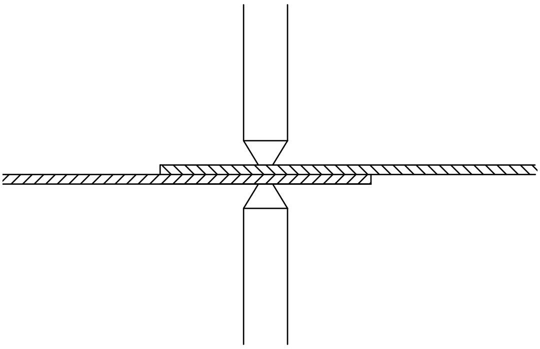


FIGURE 4.138 Resistance welding with two opposing tips.

4.18.2 Seam Welding

The continuously moving products land themselves for rotary seam welding (Figure 4.140). The weld can be continuous or interrupted.

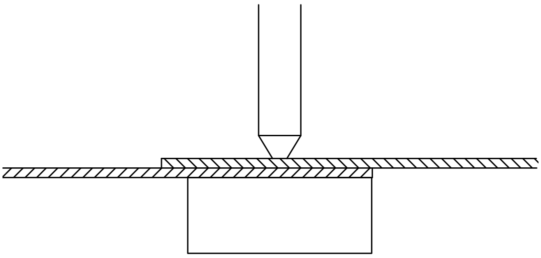


FIGURE 4.139 Large electrode surface minimizes the welding marks.

4.18.3 Other Welding Methods

Arc, induction, high frequency, plasma jet, laser, or other welding methods can be incorporated in the roll forming lines.

Arc welding requires low investment, but the welding speed is very low. On the other hand, high-frequency welding is a fast process, over 1000 ft/min (300 m/min), but the initial cost is high. The cost of high-frequency equipment is of about the same magnitude as the complete roll forming line. The cost, productivity, and weld quality of the other welding methods is usually in between the above-mentioned two technologies.

Arc, laser, and plasma welding are sometimes made on stationary finished pieces in the line, but in most cases, the continuous movement of the product is utilized for welding. For good-quality weld, it is important that the speed of the product should be uniform and be adjustable in fine increments. The weld can be straight or spiral. Spiral welding is achieved with the tube moving forward and rotating at the same time. As in all methods where edges are welded together, edge alignment is very critical. To avoid misalignment or edge waviness, usually additional roll forming passes are used.

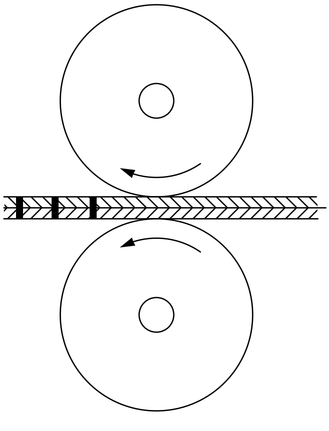


FIGURE 4.140 Intermittent rotary seam welding.

During high-frequency and some other welding processes, any stoppage can result in a large quantity of scrap. Therefore, many of the continuously welded products (usually in tubular form) run continuously utilizing a double-uncoiler, a coil welder, and a coil accumulator. Because of the high welding speeds, serious consideration must be given to product handling and packaging at the end of the line.

4.19 Painting

A large percentage of roll formed products are postpainted. In continuous operations, the products are hung from the roll forming line run-out table directly onto the paint line. In less critical applications such as structural building parts, often only a prime coat is applied without cleaning. However, in most cases, the metal has to be cleaned. In these cases, the products hooked onto a conveyor travel through a (usually) three-stage washer before priming and finish coating. In some less critical operations, the priming is omitted.

The means of hanging the product and draining the excess cleaning liquid or paint have to be considered in the design stage (e.g., punching holes in the roll forming line for this purpose only).

4.20 Foaming

Residential entrance doors, garage doors, industrial/commercial building walls, and refrigeration cabinets are frequently built from sandwich panels. The panels have light gage metal skins on the outside and foams in between. In addition to the less frequently used adhesive bonding of rigid foams (Section 4.16), the foam can be applied either in a batch process or in a continuous line.

In the batch process, the inside and outside skins are assembled together with separators. Several products are placed in a press and foaming material is injected between the skins. During curing, the foam exerts large pressure but the retaining pressure of the press prevents the bulging of the skins.

In continuous foaming process, one panel roll former is forming the inner and another roll is forming the outer skins. One of the mills is about 6 to 12 ft. (2 to 4 m) above the other one. The two panels are brought together in a shallow angle to the point where they start to travel parallel to each other. Foam is sprayed where the two panels meet. During curing, the skins are held in position by strong caterpillar type of retaining support, which moves with the panels. After curing, the finished product is usually cut to length with a flying saw.

4.21 Packaging

With the exception of products which are assembled at the end of the line into a larger product (e.g., welding a dust ring into an automotive brake component), the products must be packaged and kept together to facilitate moving into storage, transportation or retail sales.

Roof decks are just strapped together; sidings are put into a crate. Nonnesting panels and “U” and “C” channels are nested in pairs (every second one is flipped over). Studs are paired too; every ten studs (five pairs) are strapped together into a small bundle, and then from several of these ten-pack small bundles a large bundle is formed and strapped to a pallet ready for transportation.

Residential sidings, do-it-yourself products, car trims for after market, and many other products are packed at the end of the line into decorative, printed cardboard or other packages.

Because of these packaging requirements, four to six people are often involved in packaging while one is operating the line. Lately, automated packaging equipment enables running the line by one operator only, and in some places, one operator runs two or more roll forming lines, coupled with automated packaging and package removal.

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5.1 Roll Design Process

During roll forming, a flat strip is gradually formed to the finished shape (Figure 5.1). The forming is almost exclusively accomplished by rotating contoured rolls while the material "passes" through the mill.

The aim is to form the required shape repeatedly within the specified tolerances, with the least amount of "incremental steps," or, in other words, with the least amount of passes. "Too quick" forming (too few

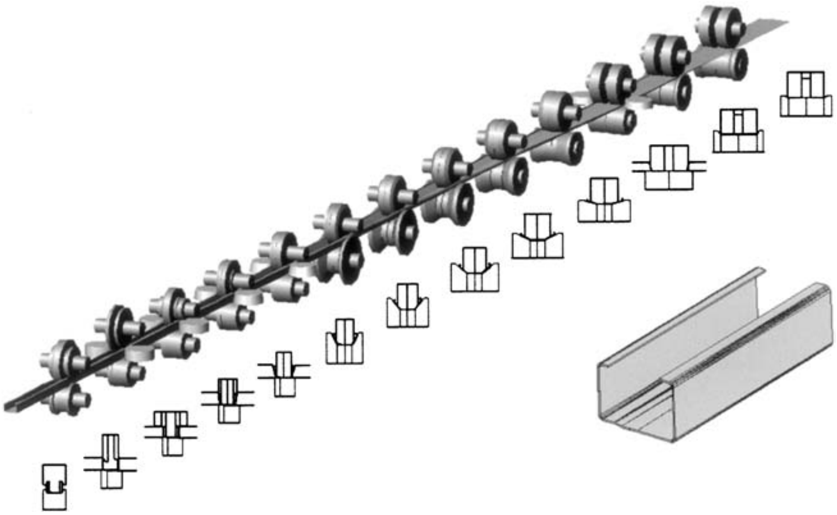


FIGURE 5.1 Gradual forming of a strip into finished section. (Courtesy of data M Software GmbH.)

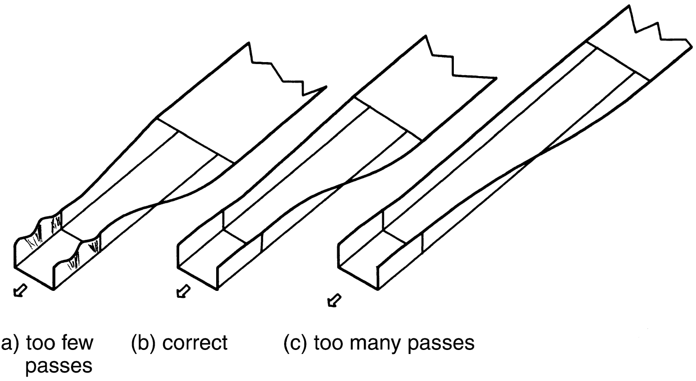


FIGURE 5.2 Too few passes form inferior products, but too many passes are prohibitively expensive.

passes) will distort the product because of the unacceptable level of stresses generated in the metal. Too many passes will make the tooling and the process uneconomical (see Figure 5.2).

After choosing orientation of the part (the position as it exits from the last pass), the designer establishes the number of passes required to form each bend. For example, a short lip may be formed in one, two, three, or more passes, depending on numerous factors. The bending may or may not be completed in consecutive passes. For example, a 90° lip may be formed in the first three consecutive passes at 30, 60, and 90°, or in two passes up to 60° and the last 30° bend (to make it 90°) will be formed in the last pass.

Then the designer establishes the flow of material. The forming may commence at the center with a bead (see Figure 5.3a) or at the edges with the short lip (Figure 5.3b) with the bead formed at later passes.

Rolls are expensive. If the designer suggests too many passes to "play it safe," then the tooling will be noncompetitive. On the other hand, having less than the optimum number of passes may result in costly roll rework, additional or roll replacement, high scrap, high setup time, or having to discard the complete set of rolls. The first and still commonly used "scientific" method for establishing the number of passes was described by Fred Gradous [55] "…The experienced roll designer doodles a bit, gazes at the ceiling and quite positively says, 'I can do it in ten'." This approach works remarkably well and most designers, based on their experience, will opt for more or less the same number of passes. Since the 1980s and 1990s, some computer-aided roll design systems have been able to recommend the number of passes or calculate the stresses created by forming. However, to date, it is still the roll designer's role to accept or modify the computer calculations and to establish the correct number of passes.

Once the number of passes, sequence, and amount of forming is settled, the designer will prepare a section drawing at each forming pass. For example, if the designer elected to form the section shown in

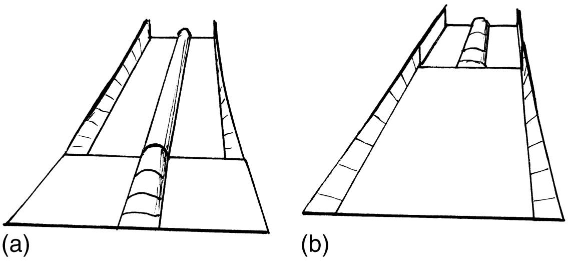


FIGURE 5.3 Forming of this section can start either with the center bead (a) or with the outside lip (b).

Figure 5.3a by starting with the center bead, formed in two passes, followed with the outside lip (three passes) and finally the larger legs in five passes, then the sequence of forming, split for better clarity, will be as shown in Figure 5.4. If the cross-sections are superimposed onto each other, then a so-called "flower diagram" is created (Figure 5.5). The top, side, and three-dimensional views (Figure 5.115) can easily be generated by the computer. When the designer is satisfied with the flow of the material, roll design can commence.

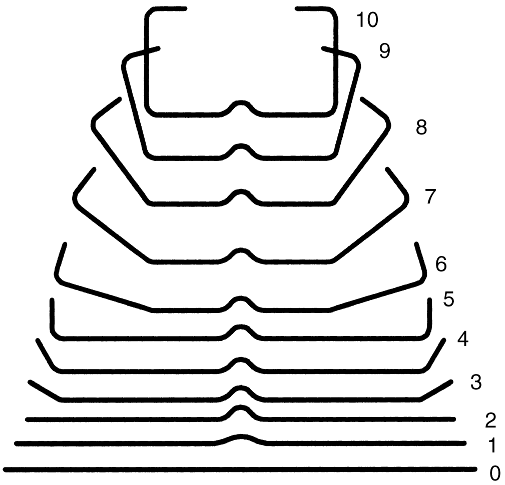


FIGURE 5.4 Split flower diagram.

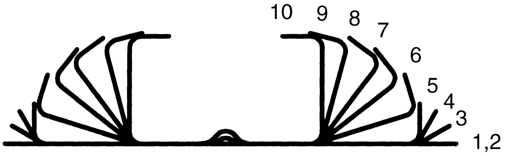


FIGURE 5.5 The usual (superimposed) flower diagram.

The variety of approaches to form even a simple section described in this chapter highlights the fact that roll design is not governed by exact rules or equations. Given the same cross-section to 10 designers, they will most probably end up with 10 different sets of rolls. Some of these roll sets will form good products, while others will not.

The probability of having a good set of "operator-friendly" rolls is to follow the basic rules: envision a smooth flow of material; do not be skimpy with the number of forming passes; avoid too short horizontal distances and too small lead-in flanges; and consider all the requirements. However, regardless of how well the set of rolls are designed, it will only work properly if the rolls are properly made, and the mill does not have bent, loose shafts or misaligned shoulders. In addition, the material to be formed has to be suitable for the process, the right type of lubricant must be used, and a well-trained operator must be assigned to set up the rolls and operates the line. If conditions are suitable, then a good set of rolls may produce millions of feet of good-quality products.

The details of this basic roll design procedure are described in the subsequent sections of this chapter.

5.2 Cross-Section

5.2.1 Complexity

The cross-section of the roll formed product is the most significant factor in roll design.

The variety of shapes is unlimited. The shapes can be arbitrarily classified as simple (open), closed, medium complex, very complex, and panel (Figure 5.6).

5.2.2 Section Depth

The depth of the section (Figure 5.7) is the maximum vertical dimension of the profile as it exits from the last pass. The depth (sometimes called "leg length" or "leg height" or "depth of corrugation") has great influence on the number of passes. In certain cases such as "folding over," the maximum vertical dimension can be at another pass ahead of the last pass (Figure 5.58). The deeper the section, the more passes are required for forming.

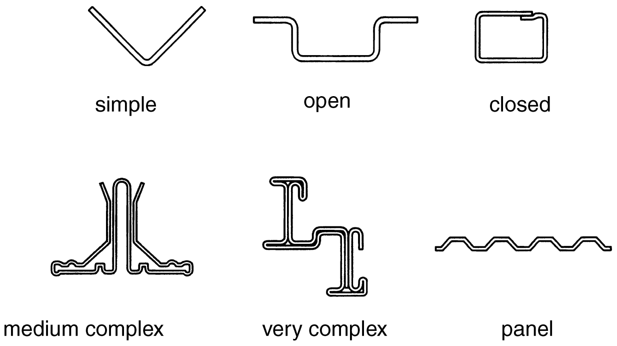


FIGURE 5.6 Cross-sections with different complexity.

Figure 5.8 shows the theoretical flow of the strip formed into a "U" channel. The length of the bend line, traveling in a straight line from point A to point B is "ℓ." The edge of the strip travels in a helical pattern for the same length as well as upward by the height of the leg (h). The length of this travel (s) is:

$$s = \sqrt{\ell^2 + c^2}$$

where c is the length of arc from point F to D, therefore:

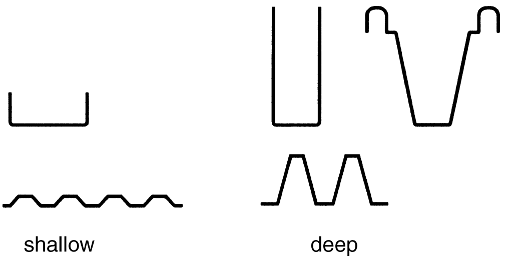


FIGURE 5.7 Shallow and deep sections.

$$s = \sqrt{\ell^2 + \frac{h^2}{4}\pi^2} = \sqrt{\ell^2 + 2.4674h^2}$$

so the elongation (difference in length between "ℓ" and "s") expressed as a percentage, in theory will be

$$e = \frac{s - \ell}{\ell} 100\% \tag{5.1}$$

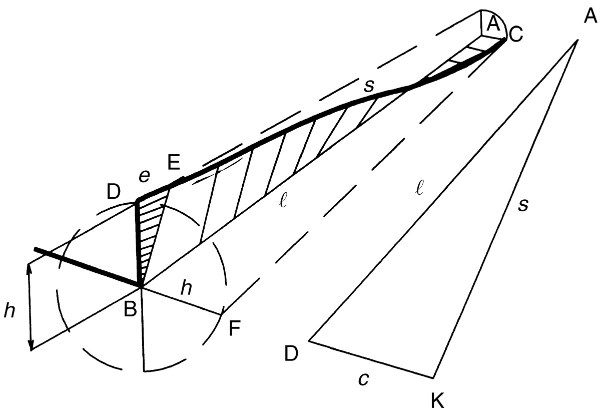


FIGURE 5.8 Schematic representation of the theoretical edge travel of a strip edge in helix pattern.

Examples

1. If a 1-in. high section is formed in four passes in a mill having a horizontal distance (between passes) of $m = 14$ in., then the theoretical elongation (e) can be calculated as follows:

$$h = 1 \text{ in. four passes } m = 14 \text{ in. therefore } \ell = 4 \times 14 = 56$$

$$s = \sqrt{56^2 + (2.4674 \times 1^2)} = 56.022 \text{ and } e = \frac{56.022 - 56}{56} 100\% = 0.04\%$$

2. If the height is increased to 2 in. and is formed under the same condition, then

$$h = 2 \text{ in. four passes } m = 14 \text{ in.}$$

$$s = \sqrt{56^2 + (2.4674 \times 2^2)} = 56.088 \text{ and } e = \frac{56.088 - 56}{56} 100\% = 0.16\%$$

3. If the section height is increased to 4 in., then

$$h = 4 \text{ in. four passes } m = 14 \text{ in.}$$

$$s = \sqrt{56 + (2.4674 \times 4^2)} = 56.351 \text{ and } e = \frac{56.351 - 56}{56} 100\% = 0.63\%$$

These examples show that increasing the leg height by 2 in., the elongation theoretically will be fourfold, and by increasing the leg height by 4 in., the elongation will be 16 times higher than the original value.

Changing the number of passes or the horizontal distance has similar effects.

4. $$h = 2 \text{ in. two passes } m = 14 \text{ in.}$$

$$s = \sqrt{28^2 + (2.4674 \times 2^2)} = 28.176 \text{ and } e = \frac{28.176 - 28}{28} 100\% = 0.63\%$$

hence half as many passes quadruples the elongation

5. $$h = 2 \text{ in. four passes } m = 7 \text{ in.}$$

$$s = \sqrt{28^2 + (2.4674 \times 2^2)} = 28.176 \text{ and } e = \frac{28.176 - 28}{28} 100\% = 0.63\%$$

If the horizontal distance is reduced to half, then the elongation (strain) will increase four times.

The above mathematical approach, based on the edge traveling on a smooth helix demonstrates the influence of the leg height, number of passes, and the horizontal distance on the strain developed during forming.

In reality, the edge travel (flow) will not be smooth, as illustrated in Figure 5.9a,b. Therefore, the actual elongation in almost all cases will be higher than the one calculated by Equation 5.1. If the strain (elongation) exceeds the elastic limit, then the permanently strained edges of the finished product will be wavy or the product will have a bow, camber or twist. Because this limit more or less coincides with Y (yield stress), one can conclude that under the same condition, materials with higher Y (yield stress) and lower E (elastic modulus) will less likely be wavy.

5.2.3 Width of Flat Elements

The width of the flat, nonformed section usually does not influence the number of passes (Figure 5.10). However, the wider the flat (not formed) section and the thinner the material, the higher the chance that waviness will occur. Regardless of how well designed the rolls are, they cannot eradicate waviness. In "Designing Products for Roll Forming" (Chapter 9), several methods are suggested to reduce or eliminate edge or center waviness.

Wide, flat, nonformed elements can create other difficulties during roll forming. If only one side of the product is formed and the rest of the strip is a wide, flat element, then a small pressure on that flat element can make it longer. The longer element will create a camber, twist, or edge waviness.

During roll forming of wide, corrugated panels, the forming usually starts at the center rib. In these cases, in addition to the progressive change of the bend angles from pass to pass, a relatively wide (up to 25-in. or 635-mm) flat sections at each side has to be moved in the same plane sideways closer and closer to the center (Figure 5.11a,b). Shifting a thin flat sheet sideways without creating large waves is not an easy task.

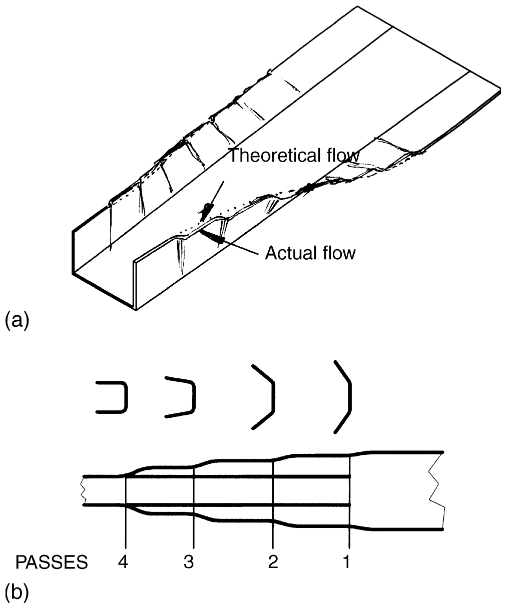


FIGURE 5.9 Actual flow is different from the "theoretical" flow.

5.2.4 Formed or Stretched Grooves

Frequently, relatively shallow grooves (flutes) are incorporated in the section design to improve appearance, minimize center waviness or add strength to the product. The grooves can be either formed or stretched into the flat area (Figure 5.12). If the grooves are formed, then they require additional blank material (wider strip). The stretched grooves take material from the adjacent areas and no additional material is required. The formed or stretched grooves can be formed in the first or in the last passes or in between. The pass in which the grooves are formed usually depends on the type of product, the anticipated shaft deflection, and the experience of the designer.

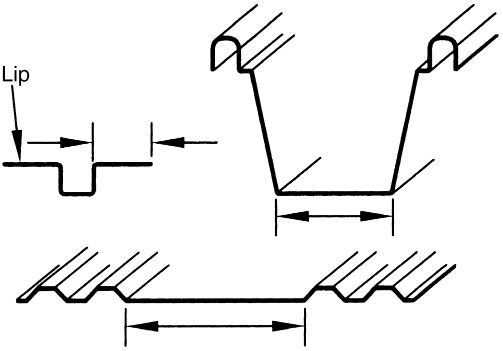


FIGURE 5.10 Width of the flat, nonformed sections has no influence on the number of passes.

When the grooves are made in the first passes, they are usually "formed" because the material "slips" in from the sides. If the flutes are stretched in the last passes, then the section is "grabbed" by the rolls at the larger cells and the material will not slip sideways into the grooves.

Another method is to stretch all grooves in one special pass. Because stretching requires considerably higher forces than roll forming, the stretching of grooves usually requires larger shaft diameters. When the material is stretched across the section, it will "shrink" in the longitudinal direction. The shortened length will help to minimize or eliminate waviness.

Stretched grooves help more to eliminate waviness, but their depth is limited by the elongation of the material. If the elongation of the material restricts the depth of the grooves, then a combination of both methods can be used. The groove can be formed to a certain depth, for example, two thirds of the final

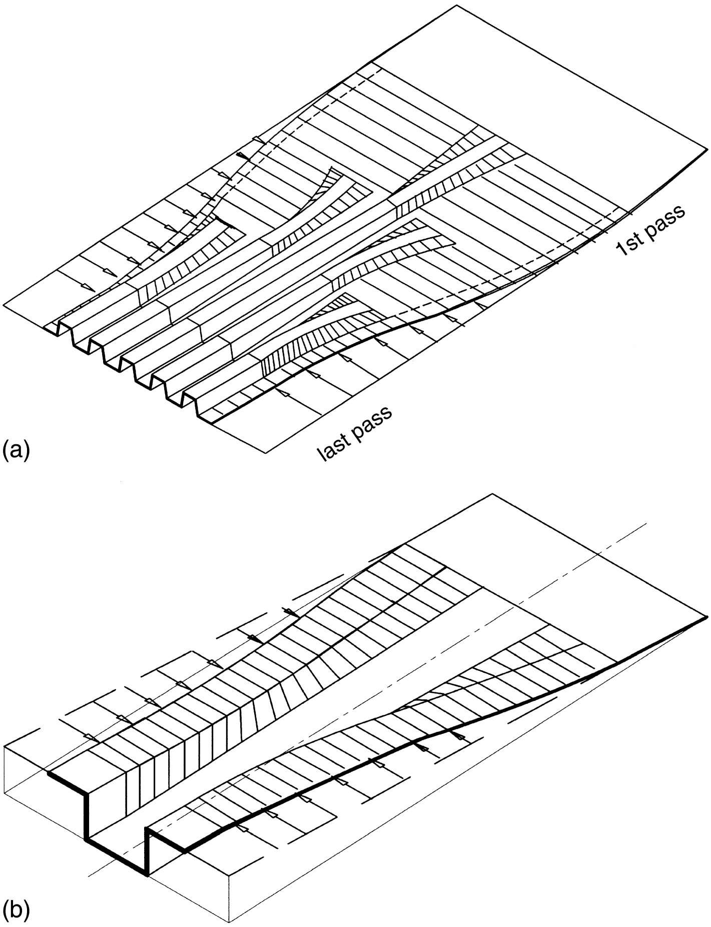


FIGURE 5.11 Wide, flat sections of a panel (a) or a section (b) move sideways to the center during forming.

depth and the last one third of the depth is stretched. This combination will provide the right depth without cracking the material.

The stretched grooves frequently create residual stresses, which result in a cross-bow of the section (Figure 5.13a). Often, compensation is needed and either the section will be formed in the opposite direction during grooving (Figure 5.13b) or, more frequently, a subsequent bending in the opposite direction is

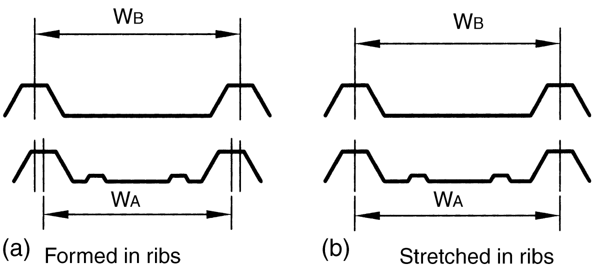


FIGURE 5.12 Formed grooves (a) and "stretched-in" grooves (b).

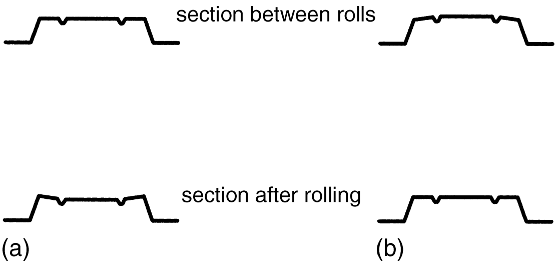


FIGURE 5.13 Stretched groove creates cross-bow (a); compensation for the bow may be required (b).

required. Stretching the groove deeper than required, then pressing it back to the final size may reduce the cross-bow.

In some cases, such as farm (barn) roofing (Figure 5.14), the cross-bow has no detrimental effect because the panel will lie flat under its own weight. Therefore, in these cases, it is not necessary to take corrective actions.

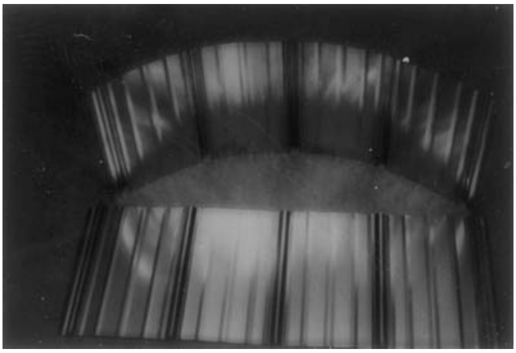


FIGURE 5.14 Cross-bow is not critical when the product lies flat under its weight.

5.2.5 Cross-Sectional Tolerances

The customer, the product designer, and the roll designer must agree on the interpretation of dimensions and tolerances specified in the drawings before roll design commences.

Product tolerances will affect the roll design, the number of passes, and thus the tooling costs. The tighter the tolerances, the more passes (and better equipment and tooling) are required.

As a general rule, the tighter the product tolerances, the greater the number of passes. The infinite variety of cross-sections and tolerance combinations make it impossible to put an exact numerical value on the increased number of passes required, but experienced roll designers have a “feel” of how many extra passes will be required to achieve the required tolerances. These additional passes frequently include the duplication of the last pass, incorrectly called the “ironing” pass.

5.2.6 Deviation from Straightness and Flatness Tolerances

Camber, bow, twist, cross-bow, herringbone effects, edge, or center waviness (Figure 10.38 -c, -d, -e, -f, -g, -h, -i, -j, -k, and -l) can be caused by the nature of roll forming (straining some parts of the section beyond the yield limit), as well as imperfections in material, equipment and setup. Tooling has great influence on residual stresses, which create deviation from straightness and flatness. Good roll design eliminates or minimizes them; bad design creates or exaggerates these problems.

5.2.7 Tolerance on Hole and Notch Locations

The roll designer must dictate the sequence of operations if holes, notches, embossments, or other changes to the strip surface are specified. During forming, certain parts of the product are under tension, while others are compressed. The difference between the overall length of the part before and after roll forming is influenced by the roll design. In some cases, the designer can proceed with prepunching the product, using the final or estimated dimensions. However, in most cases, especially with multipunch dies, it is recommended that the rolls should be tested first with “experimental” prepunching. Test holes can be punched one-by-one, cut by laser beam, EDM, or by other methods. Based on the hole location measurements before and after roll forming, adjustment can be made in the prepunching pattern. Sometimes, these steps have to be repeated until the final prepunching dimensions are established. However, it is important that the test should be carried out with the same roll pressure. Undue large pressure can thin the material and elongate the product, thus giving false test results on the hole locations.

Increased section depth, less passes, larger bend radii:thickness ratio, and larger increase in the pass-to-pass roll diameter will extend the length of product compared with the length of strip before forming. If the ratio of the total area of the bent elements to the total area of straight elements is high, and the section is formed with an adequate number of passes, then the length of the finished product will be equal to the starting strip length, and in a few rare cases, length reduction have been reported. The length reduction in these cross-sections can possibly be explained with a high Poisson’s ratio (or plastic:strain ratio) of the relatively thick material. If the Poisson’s ratio is high, then the ratio of length reduction (in the direction of rolling) is relatively high to the thickness reduction at the bend lines.

5.2.8 Surface Appearance Tolerances

Judging the appearance and establishing the level of “acceptable” surface deficiencies is very subjective. Owing to the lack of practical standards and measuring methods, the extent of acceptable scratches, marks, and other surface imperfections are usually established by “in-house” company standards. Therefore, a good understanding of the quality requirements between the customer and the supplier is essential. Several “acceptable” and “nonacceptable” samples will help to evaluate the acceptability of the product.

Hot- or cold-rolled steel is the least sensitive to surface scratches. Steels with metallic coating (zinc, aluminum, tin, etc.) are relatively good for roll forming, but precautions should be taken to eliminate the pick-up of the coating by the rolls. The best way to eliminate pick-up is to use a good lubricant and to minimize the surface speed differential between the strip and the rolls.

Prepainted metal, stainless steel, aluminum, or other metals with high luster have to be carefully formed to avoid scratches. A different roll design, more passes, different tool material or roll surface finish may be required to avoid damage to the surface. Different roll designs could include free running rolls, where the surface speed of the roll is governed by the speed of the strip. In some cases, such as the one shown on Figure 5.45, an orientation change is suggested. In this case, the high luster surface would be scratched by the rolls having substantial surface speed difference if it is rolled in the conventional way. Rotating the product 90° into a new orientation will require more passes, but at the critical surface, the strip speed and the roll speed will be almost identical thus minimizing the chances of surface scratching.

5.2.9 Length Tolerances

The length measuring method, the die accelerating system and the press have the greatest influence on length tolerance (see Chapter 3). However, other factors such as roll design can also influence length tolerance. The surface speed differential at the driving surfaces can cause uneven rolling speed. A large difference between the driven top and driven bottom roll surface speeds can increase the length tolerance by 8 to 10 times.

Examples

A roll forming mill, with one set of tooling has been used to form the shallow product (Figure 5.15a), and another set of tooling to form the deeper product (Figure 5.15b). The measured length tolerance of the postcut shallow product was within ± 0.125 in. (3 mm), acceptable for the roofs and walls of agricultural buildings. Using the same coil and making no change to the equipment, but changing the tooling to the deeper profile increased the length tolerance to ± 1.5 to 2 in. (40 to 50 mm).

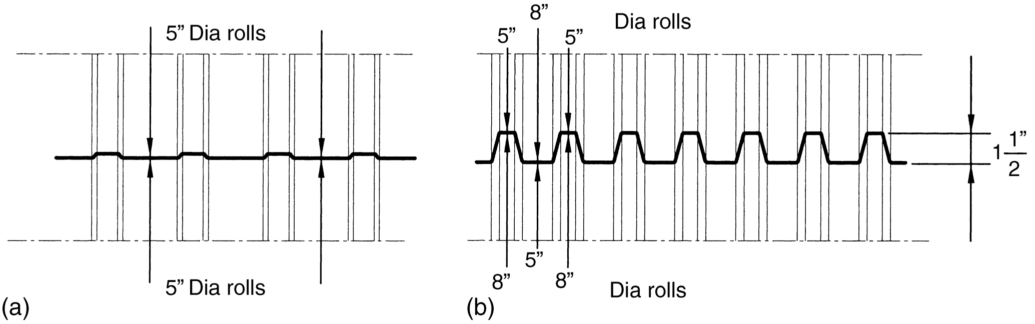


FIGURE 5.15 Same top and bottom roll diameters (a) contribute to better length tolerance, large surface speed difference between the top and bottom rolls (b) increases length tolerance.

In this example, both the top and bottom rolls of the shallow profile were 5 in. in diameter and were running at the same surface speed. The length variation resulted from the small fluctuation in length sensing, die acceleration and cutoff-press cycle of the mechanical press.

For the 1.5-in. deep sections, the roll designer selected a 5-in. diameter and an 8-in. diameter roll combination. The 3-in. difference in diameter is the result of the 1.5-in. section depth. The circumference of the 5-in. diameter rolls is 15.7 in. (399 mm), and the circumference of the 8-in. diameter roll is 25.13 in. (638.4 mm). The circumference of the larger roll is 9.4 in. (239.4 mm) longer than that of the small rolls. The shafts are rotating at the same rpm (1:1); therefore there is an approximately 9.4-in. (240-mm) surface length difference (slip) between the larger and the smaller rolls at each revolution. Depending on the change in friction, pinch, and out-of-straightness of the shafts, the speed of the panel changes continuously. When the cutting signal is given to the press and the panel suddenly accelerates, the part becomes too long. If the panel suddenly decelerates, then the part becomes too short.

The problem was resolved by using similar diameter (same surface speed) urethane rolls in the last two passes. Without making any change in the equipment or material, the length tolerance was reduced from 1.5 to 2 in. (38 to 55 mm) to ± 0.25 in. (6.4 mm).

5.2.10 Bending Radius

It is the roll designer's responsibility to ensure that the product can be formed with the bending radii shown on the product drawing. If a specified bending radius is not attainable, then it must be brought to the customer's (or product designer's) attention before roll design and blank size calculation commences.

During roll forming, the outside of the bend line is under tension and the inside is compressed in a direction transverse to the roll forming. The magnitude of the tension and compression is a function of the thickness/bending radius ratio and the mechanical properties of the material.

5.2.10.1 Small Radius

Bending most of the frequently used metals to a small inside radius (inside radius = 1 or 2 times the material thickness) results in permanent deformation with little springback. However, a too-small radius may crack the outside fiber of material having high yield and low elongation.

The minimum attainable inside bending radii are provided by the metal suppliers or are specified in standards. Although the minimum bending radii are usually established with a press-type of bending test, it is safe to apply them to roll forming. Actually, in most cases with roll forming, a smaller radius to thickness ($r:t$) ratio can be achieved.

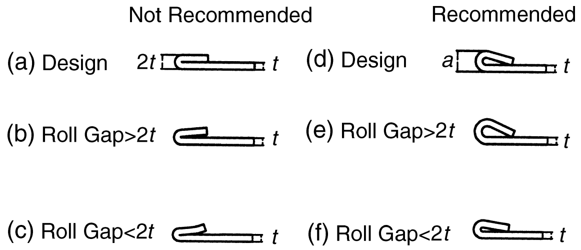


FIGURE 5.16 Hem (180° fold) designs.

Because of the method of testing, some tables show a "minimum bending diameter" to thickness ratio. This has to be converted to bending radius. For example, if the table shows that the minimum bending diameter is $t = d$, then it means that $t = 2r$, or $r = t/2$.

Folding the material back on itself by 180° bending is called "hemming." Some materials can be formed with very small, even 0 (zero) inside radius without cracking. However, it is suggested to avoid hemming with 0 inside radius even if the material does not crack. The operators will have difficulties in setting the mill roll gap to form exactly two times the material thickness (Figure 5.16a). If the gap is larger than two thicknesses ($2t$), then the hem remains open (Figure 5.16b). If the strip thickness or the roll pressure increases, then the edge can be elongated. This can create a camber in the product, make the edge wavy or "open up" the edge of the strip (Figure 5.16c). If the edge opens up, the operator may apply even more pressure, compounding the problems. Therefore, for hems, a small "tear drop" shape is recommended (Figure 5.16d–f).

To achieve a very sharp, or even a 0 inside radius, grooving (scoring) can be applied before forming. The grooving rolls are reducing the material thickness by about 30% (Figure 5.17a). Grooving rolls wear faster than the rest of the rolls, therefore to facilitate replacement, it is astute to make them as separate rolls, or make them from more wear-resistant material.

If this type of thickness reduction/grooving is used by the roll designer, then the customer should be advised that after forming, a portion of the corner will be partially "folded over." This fold, which looks like a small crack, will reduce the fatigue strength of the product. The application of scoring should also be avoided when prepainted material is formed.

Another way of achieving sharp inside bend is to form a groove into the strip as shown in Figure 5.17b. Because the material thickness is not substantially reduced at the bend line (it is not scored), less fatigue strength reduction would be expected.

For coated material, attention should also be paid to the behavior of the coating. Tables and standards provide good guidelines for the safely attainable minimum bend radii.

If the recommended minimum bending radius:thickness ratio is followed and the zinc or other coating still cracks or peels off, then the problem most probably lies in the coating process. In this case, roll modification cannot eliminate the cracking or peeling of the coating.

When the zinc coating cracks, the life of the finished product will be shortened despite the sacrificial properties of the zinc. The change in product life can be occasionally noticed on the formed edges of farm roofing ribs and other outdoor products.

Most paints and laminates do not restrict the bending radius. However, some types of less pliable paints (e.g., acrylic) and some laminates will crack or haze at the bend lines. Thus, very small cracks, similar to the above-mentioned metallic coating cracks, can lead to premature corrosion.

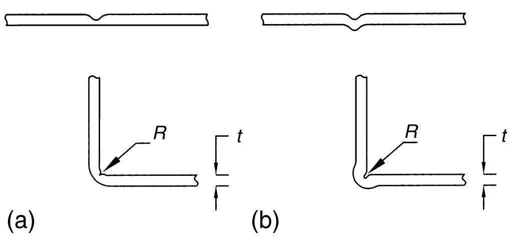


FIGURE 5.17 Two methods to form sharp inside radii.

Cracking of paints and laminates can frequently be eliminated by preheating the strip to 125 to 170°F (50 to 75°C), depending on the type of paint. Heating makes the paint or laminate pliable but not too soft for forming. It is advisable to interface the preheating process with the mill drive. When the mill slows down or stops, then the electrical or gas preheating should be adjusted or turned off. Restarting of the mill should be delayed until the material reaches the required temperature. This type of interfacing is not required if preheating is accomplished by pulling the coil through a hot water tank.

Low temperature makes some paints less flexible. Therefore, coils transported or stored at low temperatures, particularly below freezing point, may have to be brought up to room temperature to avoid cracking during roll forming.

5.2.10.2 Large Radius

A very large bending radius creates other kinds of problems. The stresses at the outside fibers are in proportion to the $r:t$ ratio. If the "r" is large, then the stress can be so low that the elastic deformation (and springback) will be more significant than the permanent one.

Therefore, it is very difficult to roll form metals with reasonable tolerances if the bending radius is 10 to 100 times (or more) the material thickness (Figure 5.18a,b). The change in thickness and mechanical properties of the metal, even within a coil, will significantly influence the radius. Therefore, designing rolls to form a product with a large radius is much more difficult than with a small radius. It may thus be necessary to resort to an approximation to the large radius using a series of flats and sharp corners (Figure 5.18c). In most cases, a better result can be achieved by using constant radius roll design and overbending the forming angles at each forming pass (see Section 5.9.3 and Section 5.9.5)

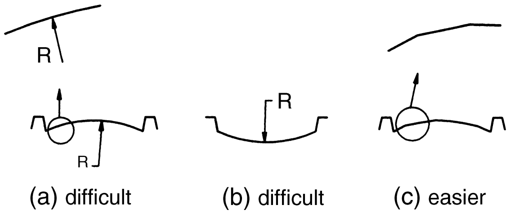


FIGURE 5.18 Roll forming products with large radius is difficult.

5.3 Product Orientation and Other Operations in the Line

5.3.1 Orientation

Before establishing the number of passes and commencing roll design, the orientation (position) of the finished section has to be established. As the section exits from the last pass, orientation is influenced by many factors. Once orientation is established, it will dictate the tool design and will influence other operations such as cutoff, punching, embossing, curving, and packaging. Some of the factors influencing, or influenced by, the orientation are listed in the following sections.

5.3.2 Forming

Unless other factors override it, the simplicity in forming will dictate the roll design: the simpler the forming, the fewer the number of passes. Some of the typical examples shown in Figure 5.19 indicate how the orientation influences the number of passes or the internal stresses.

5.3.3 Cutoff

The stroke of most cutoff presses employed in the roll forming lines is in a vertically downward direction. The roll designer may change the orientation of the section to avoid or minimize the chances of distorting the product by the cutoff blade and minimize the product/blade contact during cutoff.

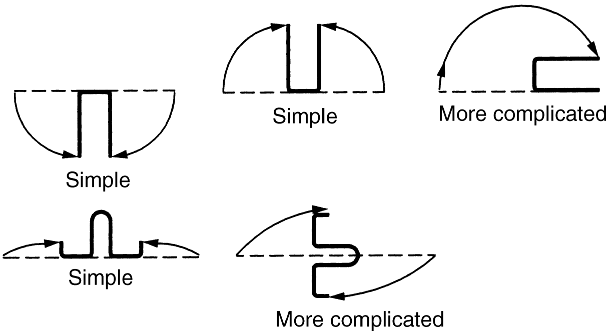


FIGURE 5.19 Simplicity in forming frequently dictates part orientation.

Long contact with the product will wear the blade quickly and will create "galling." For example, galling will drastically reduce the blade life when a 2-in. (50-mm) vertical leg is cut off with a vertically moving blade. The designer can try to reduce the shear contact by changing the contact angle. The blade/product contact angle can be changed by either "rotating" the product (different orientation) or changing the travel direction of the blade (Figure 5.20). A 15 to 30° blade travel direction (Figure 5.21a,b) is quite common when cutting off "U" or "C" channels or other sections with vertical legs.

The most frequently used methods to avoid or minimize section deformation and blade galling during cutoff are to prenotch the strip or to change the blade travel from vertical (90°) to an angular (70 to 80°) direction. Cutoff die designers occasionally employ circular or a variety of cam generated shear blade motions [188–193].

Some presses can be rotated around the axis of formed product travel. This will simplify the cutoff die design and section orientation can be dictated by other, sometimes more critical factors. If the cutoff dies also have other functions such as punching, embossing, swaging, and so on, then the direction of the stroke and the design of the die may be dictated by these factors.

5.3.4 Other Operations in the Line

The technology of other operations in the line may determine product orientation. However, slender and relatively pliable products may still be roll formed at the optimum orientation, and the product can then be twisted over a long distance to the position (orientation) best suited for the secondary operation.

(a) *Punching and Notching*. During punching, the downward movement of the punch will dispose of the slug below the surface of the strip. Punching upwards can be dangerous and should be avoided because any slug accidentally remaining on the surface of the strip can damage both the product and the tooling.

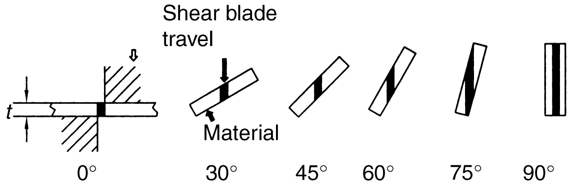


FIGURE 5.20 The length of contact between the cutoff blade and the material changes with the angle.

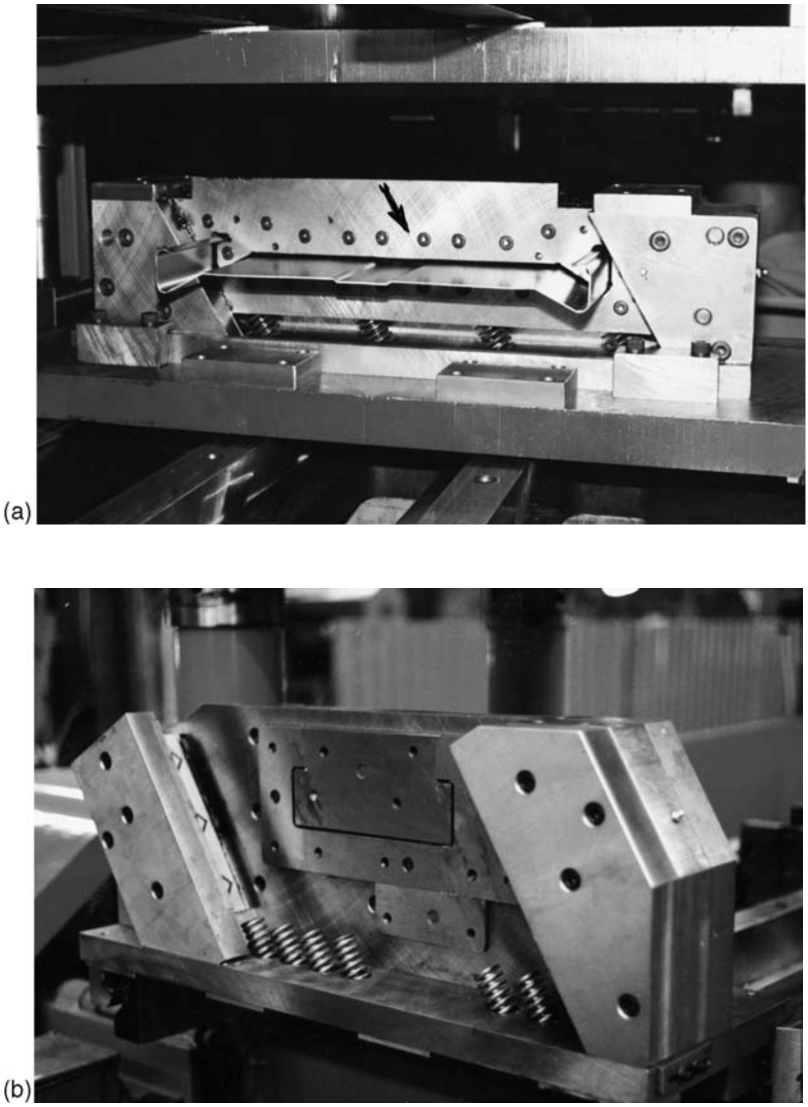


FIGURE 5.21 Cutoff blade travels at an angle to minimize galling.

The burr is also in the direction of the travel of the punch. Figure 5.22 shows the result of the punching operation. Figure 5.23 is a photograph of a shelf. The burr must be in the downward direction, and the punches above the product. Therefore, the forming of the longitudinal shelf legs is dictated by the direction in punching downwards (Figure 5.24). In some cases, a burr facing the wrong direction can be "squashed" back by passing the strip through a pair of rolls.

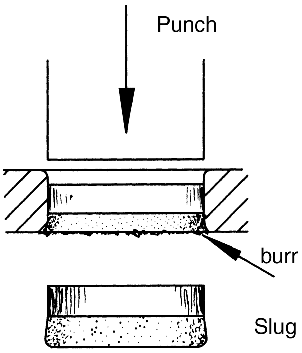


FIGURE 5.22 Punching a hole creates burr.

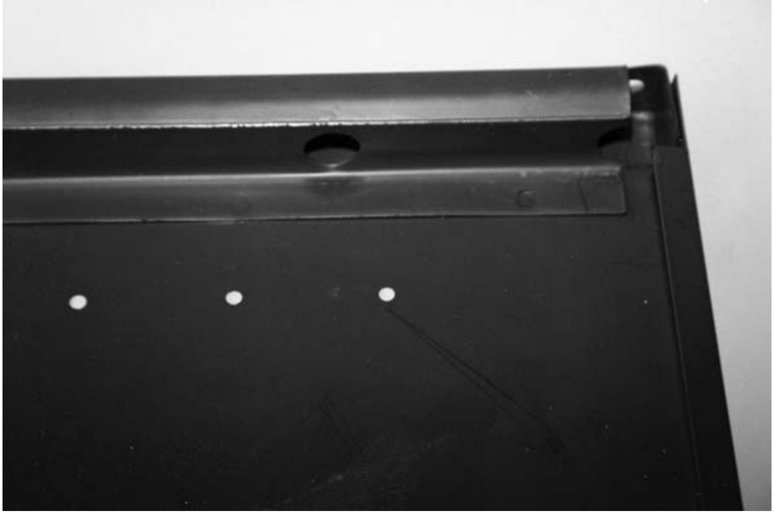


FIGURE 5.23 Shelf with holes.

(b) *Rotary Punching*. To facilitate slug removal, similar to the standard punching process, the rotary punches are usually installed in the top roll and the dies in the bottom roll. However, owing to the rotary nature of punching, if required, the direction of the burr can easily be changed upwards (Figure 5.25).

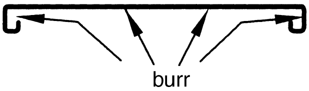


FIGURE 5.24 Shelving is formed with "legs down" to avoid burr on the top surface.

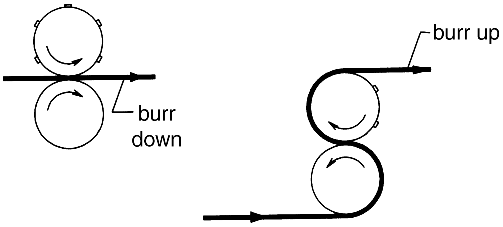


FIGURE 5.25 Direction of burr created by rotary piercing can face down or up.

(c) *Louvering, Lancing, Embossing, and Wing Bending*. These processes do not generate slugs; therefore, they can protrude from the strip up or down. These protrusions will not influence the orientation of the product. The roll designer must leave a groove in the rolls for the protrusions to pass through.

Wing benders and end benders (wipers) can operate either up or down, but because of habit, easier product transfer, and for the sake of better visual observation, the benders usually operate upwards. This means that a shelf with the ends bent up in the line has to be roll formed with legs up (Figure 5.26). In continuous shelf or similar product operation, the 90° single bends across the forming can be formed within the cutoff die (Figure 5.27). To remove the slug, the blade moves downwards and the die forms the end bend upwards. This cutoff method stipulates forming the shelves with legs up as shown in Figure 5.26.

(d) *Mechanical Joining of Different Materials*. It is not unusual for two or three different metallic or nonmetallic materials to be mechanically joined in the roll forming line. Given the continuous nature of roll forming, some of these mechanical joints (Figure 5.28a) are created by forming one material above the other ("capping"). In this situation, usually the more complex part made in a roll forming mill is at the bottom, and the slightly formed cap, formed by a second mill, is at the top.

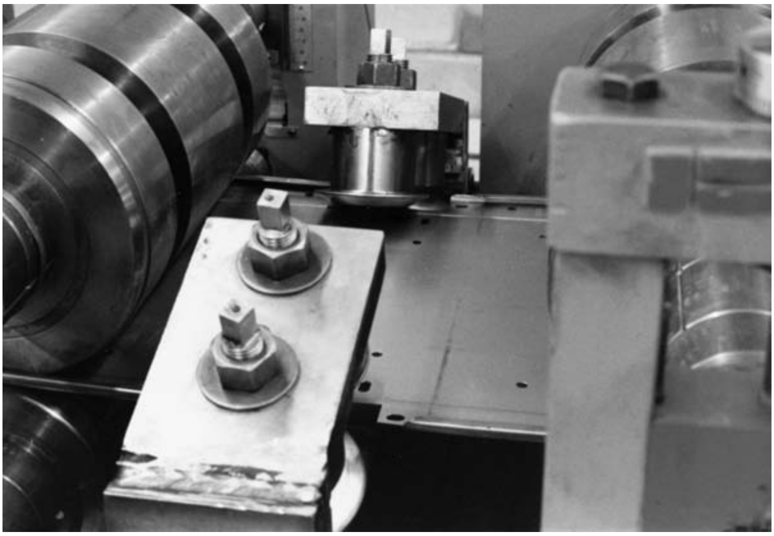


FIGURE 5.26 Shelves are formed with leg up if required for end bending.

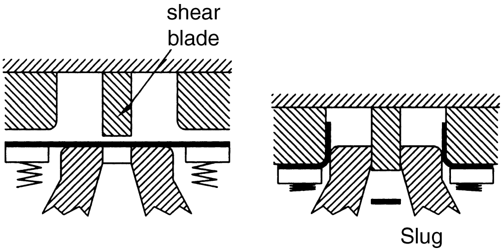


FIGURE 5.27 Bending ends of products across the direction of rolling.

The two parts are tangentially brought together and finally formed at the later part of the mill. Different materials can also be stitched (Figure 5.28b), clinched (Figure 5.28c), lock-seamed (Figure 5.28d) or joined together by other methods (Figure 5.28e–h). These operations will influence the orientation of the part.

(e) *Marking and Coining*. Product identification (marking) and continuous or intermittent coining (local thickness reduction) of the material can easily be accomplished on both top and bottom surfaces. If marking is made by embossing or stamping identifications into the material, then the roll designer must ensure that these markings are not obliterated at subsequent passes. For better visual observation, most markings, including attaching of adhesive labels, are applied to the top of the product.

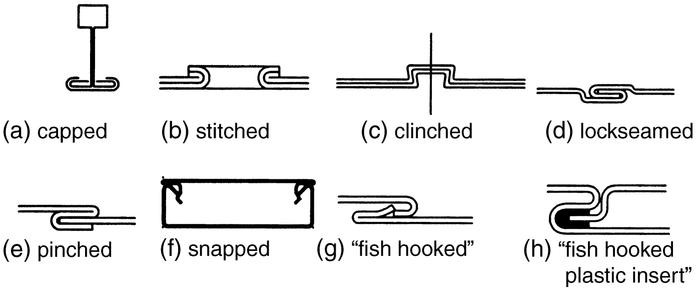


FIGURE 5.28 Examples of joining different material mechanically without fasteners.

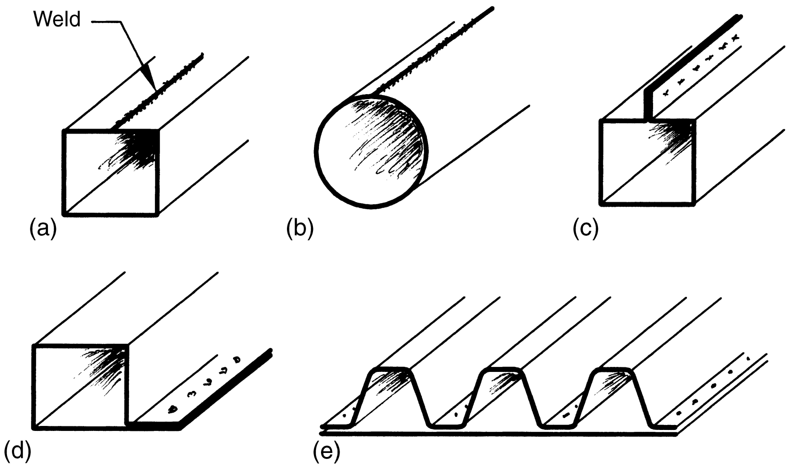


FIGURE 5.29 Welded roll-formed products.

(f) *Curving and Sweeping*. The distance from the roll forming mill bed (or from the floor to the pass line height) does not usually allow for the product to be curved downwards. Therefore, in most cases, the product is curved upwards or sideways. The direction of curving (sweeping) will dictate the orientation of the product in the roll forming mill.

(g) *Welding*. When high frequency arc or laser welding is used in the line, the weld is usually made at the top of the product (Figure 5.29a,b). Resistance welding (spot or continuous) can be made at any position (Figure 5.29c–e). Both the technology and the visual checking of the welding process often dictate the part orientation.

(h) *Caulking and Applying Adhesives*. To minimize spillage, caulking of grooves or cavities is usually made from the top (Figure 5.30).

To facilitate visual observation, sprayed, roller coated or otherwise applied adhesive are usually, but not exclusively, applied to the top surface.

(i) *Foaming*. When foaming is continuously applied to products such as insulated panels and doors, the two outer skins have to be roll formed with their inside, usually horizontal surfaces, facing each other. Orientation is less critical for parts cut before batch foaming using automated or manual handling.

(j) *Extruding*. If rubber, plastic, or similar material is extruded onto the roll formed product, then the simplicity in roll forming usually dictates the product orientation. If the product has to be cleaned before entering the extrusion head, then the discharge of the cleansing liquid may be a consideration (legs facing downwards).

(k) *Other Processes*. Other processes such as interleaving, packaging, automated material handling, automated placement of the roll formed parts into the next operation, and others may have an important influence on the orientation of the product.

Products cut to length before these operations may be “flipped over” after roll forming. Occasionally, for better “nesting,” every second product is flipped (turned) over during packaging.

(l) *Visual Observation*. It is frequently specified that critical painted or high gloss surfaces should be on the top side to help visual observation.

If forming, leg lengths, hole locations, or other features are more important at one edge than at the other, then the critical edge should be at the operator side of the mill.

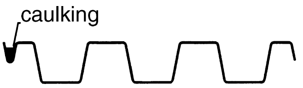


FIGURE 5.30 Caulking building panel in the line.

5.4 Materials

5.4.1 Effect of Material on Roll Design

Materials are selected to suit the specified product requirements at the possible lowest price. However, the mechanical properties, surface, deviation from thickness, width, straightness, and flatness of the material will influence roll design.

A detailed description on the most frequently roll formed materials is in Chapter 6.

5.4.2 Mechanical Properties

During roll forming, the strain (elongation) of the outside fiber of the strip must remain below the uniform engineering strain. Therefore, the roll designer must know the yield strength, maximum tensile strength, and elongation of the material. These data are usually available from the supplier.

In low carbon steel, the correlation between hardness and tensile strength is reasonably good. Therefore, hardness is sometimes used to "check" the incoming material and "screen out" the too "hard" or the too "soft" steel. However, "good hardness" does not guaranty good formability.

Cold work (plastic deformation under the annealing temperature) such as bending, tensioning, compressing, and other operations will increase the yield and tensile strengths and reduce elongation. Cold working of some materials, for example, certain stainless steels, zirconium, and other special alloys significantly increases the yield and tensile strength (Figure 6.11).

Based on past experience, the roll designer can usually judge the anticipated formability of the material, including the minimum radius and springback. However, the highly work-hardening materials may have similar mechanical properties to mild steel before roll forming, but by the time bending is completed, the properties are closer to high strength steels. The result can be a 15 to 25° springback at a 90° bend instead of 1 to 2° normally associated with material having similar starting mechanical properties.

Materials having high yield strength, small difference between tensile and yield stresses, and small elongation require more forming passes.

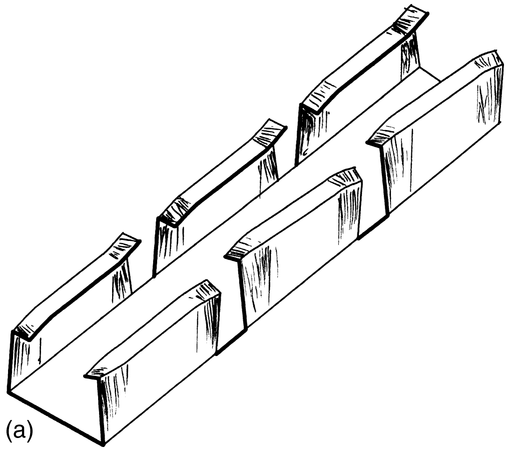
5.4.3 Springback

In addition to the mechanical properties of the material, springback is influenced by the $r:t$ ratio, the method of forming, and by the elastic modulus (E) of the material (Table 6.1; see also Section 5.12.12).

5.4.4 Flare

(a) *General Observations*

- Flare is a change in the cross-section at the cut ends of a roll formed product.
- The angular change can be towards or away from the center line of the section. In the case of lower strength materials, not too-deep sections and especially with precut blanks usually the front end is "flared in" and the tail end is "flared out."
- Deep or high strength materials usually flare out at both ends (Figure 10.38c).
- Noticeable flare may start only 0.5 to 1 in. (12 to 25 mm) or, in extreme cases, 24 to 36 to 48 in. (600 to 900 to 1200 mm) from the ends of the finished section.
- The section width increase caused by the flare can be from a few thousands of an inch (0.025 to 0.1 mm) to 0.5 to 1 in. (12 to 25 mm).
- The worst flare observed by the author was approximately 4 in. (100 mm) in width.
- The flare is usually larger when precut blanks are roll formed.
- Flare does not depend on the method of cutting. Continuously formed sections cut with flame, saw, or cutoff die will show the same flare.
- The deeper the section, the larger the flare will be.



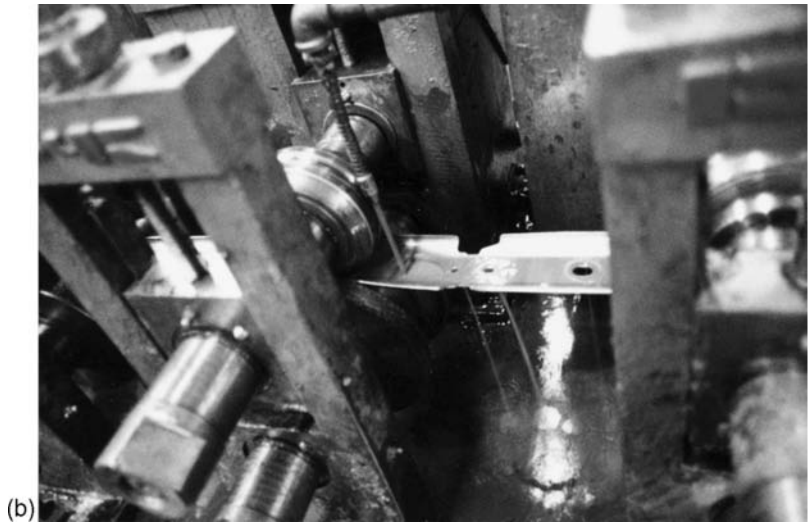


FIGURE 5.31 Deep cutouts have the same effect on flare as cut ends. (a) Schematic representation; (b) cutouts between passes. (Courtesy of Delta Engineering Inc.)

- The higher strength the material, the larger the flare will be.
- The more abrupt the forming is (fewer passes, shorter horizontal distances), the larger the flare will be.
- Deep notches at the edges will create flare, similar to precutting (Figure 5.31a,b)

(b) *Problems Caused by the Flare.* It is obvious that a change in width and angle can create problems in joining parts together (like assembling components), butting them side-by-side (like building panels) can create product application and appearance problems.

(c) *Cause of the Flare.* The flare is caused by internal stresses which are balanced while the section is continuous, but become unbalanced as soon as the section is cut. The author has neither sufficient data to specify these internal stresses nor information on how to eliminate them in every profile. However, the factors influencing flare can frequently be identified.

(d) *Increasing, Reducing, or Eliminating Flare.* Flare in certain profiles will be increased if:

- Not enough forming passes are used, especially to form the edges.
- Horizontal centers are too close, especially in deep sections.

- Side-roll passes, placed between the main passes, used for edge forming or overbending are at a too short horizontal distance.
- Inward travel of the edges is extensive at the last passes (Figure 5.32) and, after the last pass, it changes suddenly in the direction of the flow.

Many roll suppliers claim that they have methods to eliminate flare. Some of the recommended and often proven techniques are:

- Use more passes, mainly to form the edges.
- Use a mill with larger horizontal centers especially when forming deeper sections.
- Overbend slightly and then bend back the legs as shown in Figure 5.33. This will give an opposite "bending moment" to the edges.
- According to one report, a similar effect has been achieved using an unusual "concave" side (dovetailed) main top roll and adjustable side rolls (Figure 5.34).
- Use "gentle" forming at the last few passes.
- Apply two identical "last passes."
- Use three roll straighteners designed for the edges only.
- Apply force to squeeze (crash) the outside legs and the bend lines. In some cases, varying the pressure will change the flare from outwards to zero, or even inwards at one end and opposite at the other end of the product.
- Preform bends with slightly larger than the required final radius, then reduce the radius in the last forming pass(es) [414].

5.4.5 Material Tolerances

5.4.5.1 Thickness

The material must be able to pass through the gap between the rolls without thickness reduction. Therefore, roll gap is calculated as the sum of the maximum specified thickness plus maximum

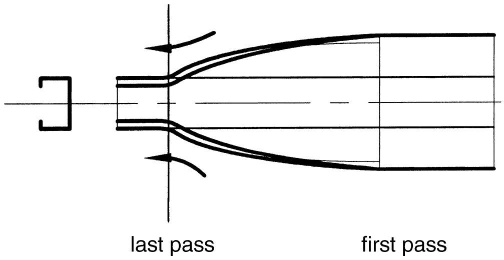


FIGURE 5.32 Too much forming at the last pass will increase flare.

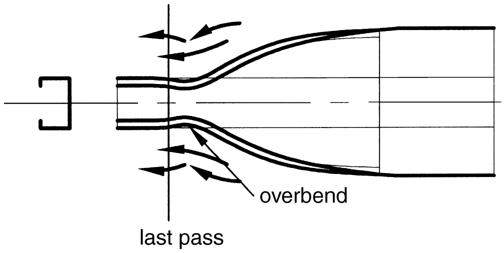


FIGURE 5.33 Overbending before the last pass and bending out at the last pass usually reduces flare.

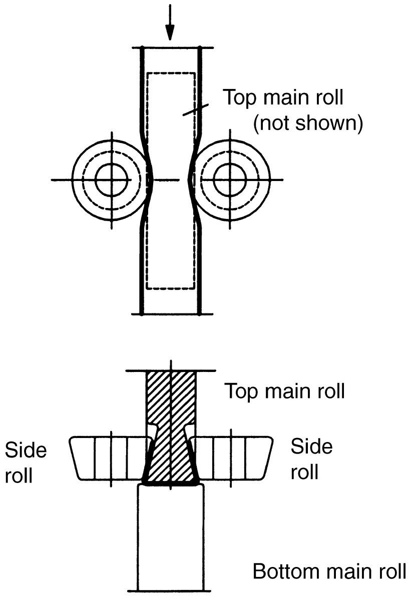


FIGURE 5.34 This unusual "overbending" creates similar effects as the one shown in Figure 5.33.

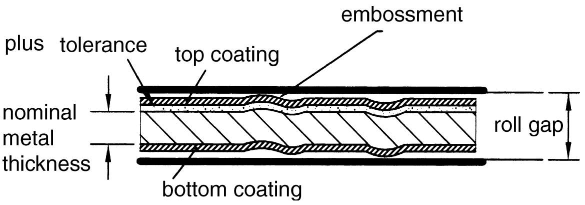


FIGURE 5.35 Maximum material thickness used for roll design.

thickness tolerance plus maximum coating thickness plus the maximum depth of embossing (if any).

$$\text{Roll gap} = \text{max. thickness} + \text{max. tolerance} + \text{max. coating thickness} + \text{max. embossing depth}$$

(see Figure 5.35).

Attempting to roll form thicker material than the specified maximum thickness could break the rolls, damage the equipment, reduce the quality of the product, and create waviness, scratches, or other problems.

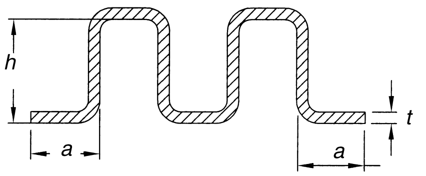
The thickness also affects the blank size (strip width). The blank size and dimensions are calculated for the mean thickness. If the thickness is at the maximum plus tolerance, then some dimensions will be smaller. If the thickness is at the minus tolerance, then some dimensions will be larger.

Example

The profile shown in Figure 5.36 has eight 90° bends (giving a total of 720° in the bends). The material thickness is 0.100 in. (2.54 mm), and $r:t = 1$.

The bending starts at the center rib. A typical ±0.006-in. (0.15-mm) thickness tolerance allows the thickness to fluctuate between 0.106 in. (2.69 mm) and 0.094 in. (2.39 mm). Designing rolls for the 0.094-in. (2.39-mm) thick material and for the same product dimensions, the blank width would be 0.075 in. (1.91 mm) less.

The usual practice is to design the rolls for one thickness and use the same blank size for both the maximum and minimum thickness (in this example, nominal ±0.006 in. [0.15 mm]). As a result, for a profile with one cell at each side of the center line, the two outside lip dimension would fluctuate by ±0.050 in. (1.27 mm). This is based on the assumption that the operator is not adjusting the roll gap to suit the change in material thickness. This means that at the minimum thickness, the height of the section will be 0.006 in. (0.15 mm) less than what is required, and an additional 0.050 in. (1.27 mm) will have to be added to dimension "*a*" at each side. If the panel has eight cells (four at each side of the center line),



t=0.100±0.006" (2.54± 0.152mm)and roll gap not adjusted

if t=.106"(2.692 mm) then a= 1.050" (26.67 mm)
if t=.100"(2.540 mm) then a= 1.000" (25.40 mm)
if t=.094"(2.388 mm) then a= .950" (24.13 mm)

Change in dimension "a"=9.94 x (change in material thickness)

FIGURE 5.36 Material thickness tolerance influences product dimensions (top roll position not changed).

then the "*a*" dimension can fluctuate ± 0.200 in. (5.08 mm). However, adjusting the roll gap will reduce this fluctuation. This example also proves that by forming material with tight thickness tolerance the dimensional tolerance of the outside lip will be much tighter.

The above calculation proves that tight material thickness tolerances are necessary to roll form sections to tight tolerances. In other words, if the material thickness tolerances are loose, then it is difficult, if not impossible, to manufacture products to tight sectional tolerances.

A change in thickness also has other implications. The gaps between the rolls are designed to form the product with the maximum material thickness (Figure 5.37b). Feeding thicker strip between the rolls than the roll gap can break the rolls or yield unacceptable product. Reduced thickness can make noticeable changes in the shape (Figure 5.37a,b), especially if the roll gap is not reduced. Adjusting the roll gap to the thinner material helps but angular changes will still occur. A reasonably large change in the $t\!:\!r$ ratio will also affect the springback.

Some rolls are designed to form products made from one specified thickness. Rolls for some older building products have been designed to form materials from 0.018 to 0.108 in. (0.46 to 2.75 mm), a thickness ratio of 1:6. The large change in thickness results in changing in shape and coverage. At some points, shims are used to correct the coverage. If the rolls are designed for the thickest material with a $t\!:\!r = 2$, then the same rolls will form the thinnest material with a $r\!:\!t = 12$. The larger $r\!:\!t$ ratio will yield a larger springback and can adversely affect the web crippling resistance of the product.

The thickness tolerances for aluminum coils/strips are reasonably tight but the "standard" North American steel tolerances are loose. The tolerance can be more than ± 10% of the material thickness. Steel mills are able to supply coils with considerable better tolerances then the specified standard. However, to guarantee tight product tolerances, roll formers, especially those in the automotive, aerospace, appliance, furniture, and other industries are pressing the suppliers to provide coils with so-called "half," or occasionally "quarter" thickness tolerances without extra charges. This means that instead of, say, ± 0.004-in (0.1-mm) thickness tolerance, the steel should have ± 0.002-in. (0.05-mm) or even ± 0.001-in. (0.025-mm) tolerance. The thickness tolerance of a coil also depends on how close to the edges can the measurements be taken.

5.4.5.2 Width

Width tolerance will obviously influence some dimensions of the product. In most cases, the strip width tolerance will be added to the roll forming tolerance at the outside lip (the element from the strip edge to the first bend). If this dimension is critical and is tightly controlled, then the extra material may gather at the center, creating waviness and other problems.

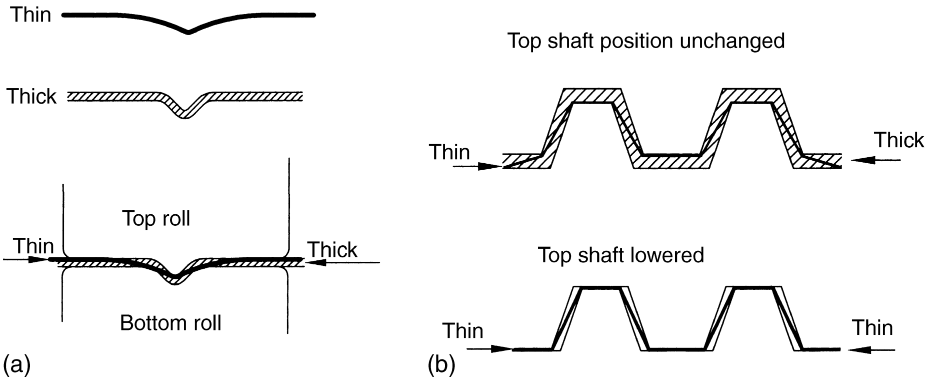


FIGURE 5.37 Change in thickness will change section dimensions (a). Adjusting roll gap restores height, but it does not eliminate angular changes (b).

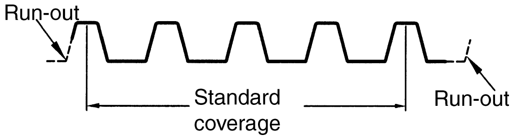


FIGURE 5.38 Room for "runout" should be provided in most panel tooling to allow the use of wider coils.

For building products (roofing, siding etc.), the typical +3/16 in. −0 in. (+4.75 −0 mm) mill tolerance does not represent any problem. All the extra material is to increase the width of one or both lips. Actually, for building products, it is highly recommended to provide additional "runout" for an extra 0.5 to 1 in. (12 to 25 mm) of material (Figure 5.38). This "runout" (additional strip width space) in the rolls and in the cutoff die will permit the use of wider material when required. Wider material may be purchased as a substitute in case of material shortage or for other reasons. For example, if the blank size is 35.4 in. (900 mm), then, in case of emergency, the more readily available standard 36-in. (914-mm) wide coils can be used. Suppliers do not usually charge extra for this "runout" in the rolls and cut off die.

For narrower slit coils, the typical ±0.005-in. (0.013-mm) slitting tolerance is acceptable. However, the roll designer must bear in mind that even this total 0.010 in. (0.25 mm) difference between the maximum and minimum width will permit the strip to "wander" between the entry guides and between the traps in the rolls, which have to be designed for the maximum width. This means that the 0.010-in. strip width tolerance has to be added to the normal roll forming tolerances. If this is not acceptable, then a tighter slit width tolerance is required. If only one edge of the product requires tighter tolerance, then spring-loaded entry guides or tight entry rolls positioned at a skewed angle, which forces the strip against one side, can be used with the strips slit to "standard" width tolerance.

5.4.5.3 Camber

Camber is the deviation of the strip edge from a straight line in the horizontal plane. The inside concave edge of the strip is shorter than the outside convex edge. During the roll forming process, the strip is straightened. The shorter edge (marked "S" in Figure 5.39) will be under tension and the longer edge (marked "L") will be compressed. Depending on the conditions, the compressed edge may become wavy.

It has not been recognized for long time that camber is a possible contributor to product problems. However, roll formers are now requesting tighter camber tolerances because rolls cannot be designed to compensate for camber. Special devices such as automated camber correctors for narrow strips and special levelers for wider strips can eliminate or minimize the effect of camber.

Excessive camber also creates problems when the strip is prepunched in a long prepunching/notching die. Because the punches are set in a straight line, the hole distance from the edges will vary according to the camber in the strip (Figure 5.40a). During roll forming, the strip is straightened; therefore,

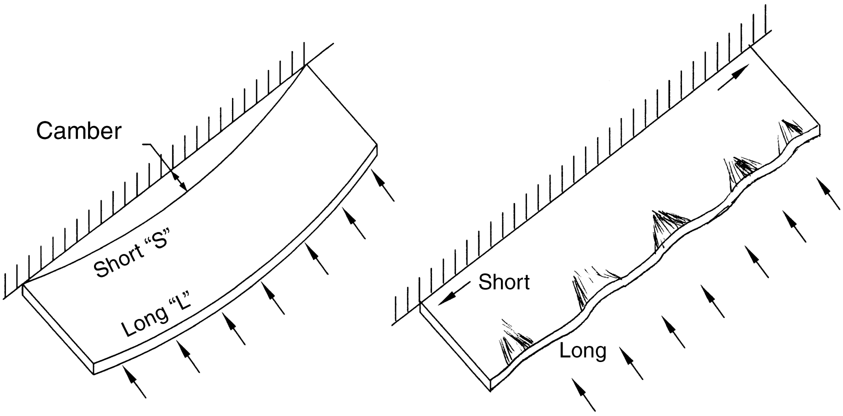


FIGURE 5.39 When a strip with excessive camber is straightened, the longer (outside) edge will be wavy.

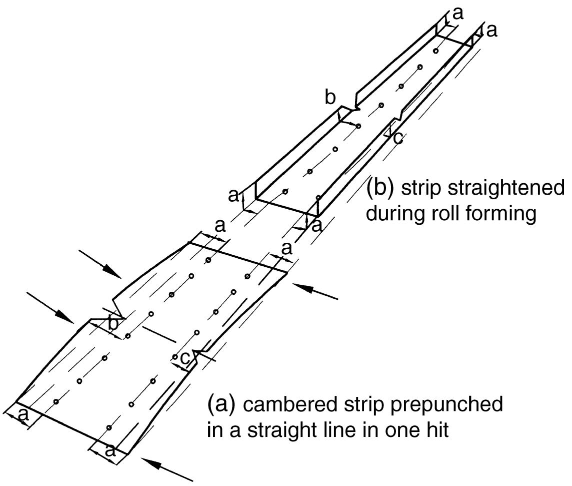


FIGURE 5.40 Holes punched in a straight line in a cambered strip will appear in a curved "scallop pattern" and notches will be off bend lines after roll forming.

holes prepunched in a straight line will be on a radius similar to the radius of the camber in the strip (Figure 5.40b).

In the case of thin, narrow strips, the guide in the prepunching die may straighten the strip during punching. Thicker, wider or higher strength cambered strips may get stuck in the prepunching die, which has a guide built to the maximum strip width tolerance. If the strip guides are made wider, then the tolerance on the hole locations from the bend lines will be looser.

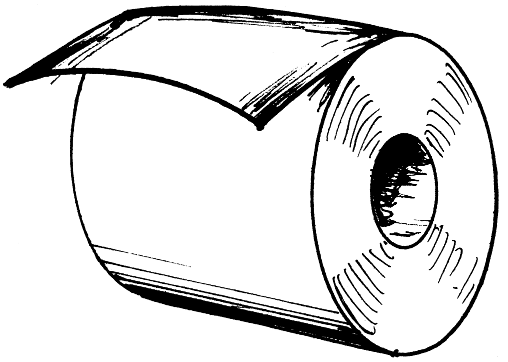


FIGURE 5.41 Cross-bow in coils may show up in some finished products.

5.4.5.4 Cross-Bow (Crown)

As a result of steel-making technology, some thicker coils will have a cross-bow (Figure 5.41). This cross-bow (or crown) makes it difficult to feed in the end of the coil and can show up in finished product having a wide flat surface. Roll designer cannot compensate for this cross-bow, but a flattener placed in front of the mill will practically eliminate it.

5.4.5.5 Longitudinal Bow

Thick, higher strength coils are permanently curved in a longitudinal direction during the coiling process (Figure 5.42). The magnitude of the longitudinal bow changes within a coil, the closer to the center, the more severe the bow will be. To feed this type of coil into the mill, a flattener is required. A flattener will also be required when

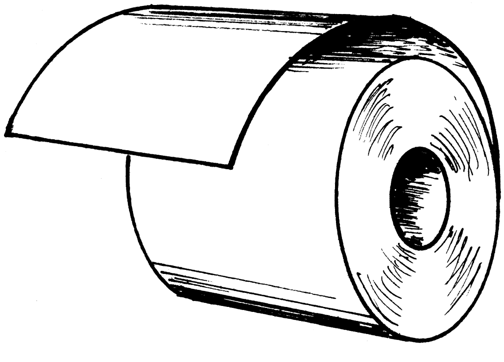


FIGURE 5.42 Permanent longitudinal bow.

coil ends are welded together or the product is prepunched.

The longitudinal bow is usually considered during roll design. A finish product straightener may compensate for the residual stresses left in the product after strip flattening and roll forming.

5.4.5.6 Twist

During roll design, it is assumed that the incoming material does not have twist. Rolls are not designed to compensate for the twist in the material.

When an asymmetrical section is roll formed, the finished product will have a twist after leaving the last pass, even if the starting material is flat. In some most unusual cases, roll formers may minimize this twist by twisting the strip in the opposite direction before it enters the mill (Figure 5.43). This pretwisting is only applicable to certain thickness:width ratios, strength, and when space is available for twisting. It must create a permanent twist in the strip but should not create a problem when the end of the strip is fed into the line. Trying to twist relatively thin and wide material may create unwanted permanent edge elongation.

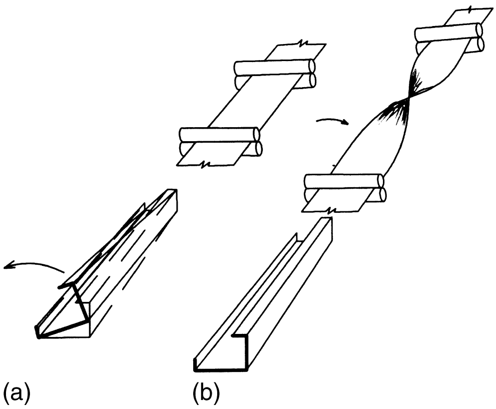


FIGURE 5.43 Twist in the finished product (a) occasionally can be reduced by twisting the strip in the opposite direction (b).

A more common method to compensate for the anticipated twist is to "twist" the product in the opposite direction in the mill, from pass to pass. This principle is used when forming "Z" sections (Figure 5.44). In other cases, the "countertwisting" is accomplished just in the last one or two passes. The most frequently used method to eliminate the twist is to apply an adjustable "straightener" after the last pass.

5.4.5.7 Waviness

Starting material with wavy edges will most likely yield products with wavy edges. Panels and other flat products made out of center-wavy material will be center-wavy. Rolls cannot take out waviness, but incorrect roll design or incorrect setup or equipment can induce waviness in the finished product.

Coil center-waviness or edge-waviness may be corrected by passing the coil through a special "corrective" leveler ahead of the roll forming mill. These flexible levelers can "elongate" certain parts of the coil, thus eliminating waviness in the strip or making either the edges or the center wavy if required.

It is important to know that tension-leveled coils, which have excellent flatness tolerance as sheets, have considerable but balanced internal stresses. The balance is broken by the bend lines during roll forming and it is possible that a previously flat segment of the strip becomes wavy. Again, roll designers cannot

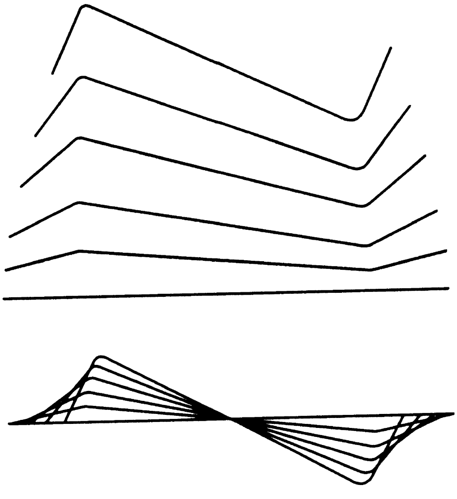


FIGURE 5.44 Forming a "Z" section with the web gradually twisted in the opposite direction will eliminate twist in the finished product.

design rolls to compensate for this waviness. However, as mentioned above, incorrect design can create waviness.

5.4.5.8 Surface

The surface appearance requirements of the finished products and the surface of the starting material will influence the roll design. Hot-rolled, hot-rolled pickled and oiled (HRPO) and cold-rolled steels are the least sensitive to surface scratches and require the least amount of precaution. If low melting temperature metallic coating such as zinc, aluminum, or tin has been applied to the base metal, then forming requires more precaution to minimize the "pick-up" of the coating material on the rolls. The roll designer should aim to minimize the speed differential between the rolls and the formed material, and the roll former must apply good lubricant. For further details, see Chapter 6 "Materials" and Chapter 7 "Lubrication." Prepainted material does not usually require special consideration but it is prudent to minimize the surface speed differential wherever possible. Using the same rolls for forming both galvanized steel and prepainted steel is nor recommended. Zinc pick-up on the rolls will scratch the prepainted surface.

Hot-rolled steel with scale (not pickled) must be formed with rolls made from D2 tool steel because of the highly abrasive nature of the iron oxide. Other tool materials will wear very fast. In extreme cases, tooling made from 01, L6, or similar material may be rendered useless after 50 to 100 hours of roll forming hot rolled steel with scale.

Some laminates can be relatively thick, for example, 0.010 in. (0.25 mm) or more. The designer must provide sufficient roll gap for the total material thickness including the laminate. If the customer specifies 0.024 ± 0.003-in. steel with 0.010-in. thick laminate, then the roll gap should be

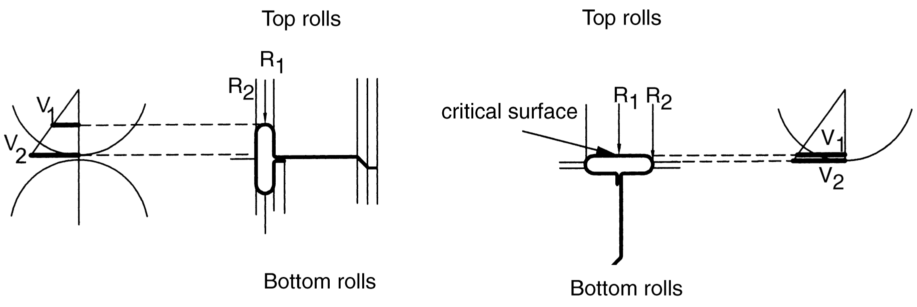
$$0.024 + .003 \text{ in. (tolerance)} + 0.010 \text{ in. (laminate)} = 0.037 \text{ in. } (0.61 + 0.075 + 0.254 = 0.94 \text{ mm}).$$

Operations with extreme roll pressure on prepainted or laminated material should be avoided.

Glossy and other surfaces sensitive to scratches should not be formed with high pressure or with high surface speed differential. To minimize the roll pressure, the forming of prepainted, laminated and high luster surface material has to be accomplished in more passes. Frequently, more side-roll passes with free running rolls will help eliminate surface scratches or other blemishes.

For example, a product would traditionally be formed as shown in Figure 5.45a. However, the speed differential between parts of the rolls and the product will mar the product surface. Therefore, it is recommended to change the product orientation as shown in Figure 5.45b. In this way, more passes will be required but the speed differential between the strip and the top roll will be negligible. In both cases, the application of several nondriven side-rolls can minimize the surface mark problem.

A polished, high luster roll surface, occasionally different roll material (bronze, plastic) as well as good lubrication can help to eliminate or minimize surface blemishes or scratches.



(a) Traditional orientation

(b) improved orientation

FIGURE 5.45 Critical, high luster surface of a product can influence product orientation.

The surface of embossed materials usually does not cause difficulty in roll design. The material can be roll formed as usual but extreme pressure must be avoided.

When products with sensitive surfaces are roll formed, special precaution must be taken at all components of the roll forming line. Entry guides, side-roll stands, straighteners, cutoff dies, and other guides may leave unacceptable scratch marks unless they are properly designed and are made from the right material.

5.5 Roll Forming Mill

5.5.1 Influence of Roll Forming Mill on Roll Design

Rolls are designed to form the material and they must match the roll forming mill.

The roll designer must have all the relevant equipment dimensions and other data which can influence roll design. Table 5.1 (Sheet 1 and Sheet 2) show a typical questionnaire for “standard” mills. Missing or misinterpreting any data or dimensions can be very costly.

5.5.2 Type of Mills

(a) *Cantilever (Overhanging) Mill.* This type of mill limits the formable strip width to about the length of the short shafts. The rolls can be slightly extended beyond the shaft length but this method is not recommended. The further the forming forces are from the support bearings, the larger the shaft deflection will be.

If only one edge of wide strip is to be formed, then the opposite edge should be properly guided. In this case, it is more practical for all the material used for forming to be taken from the drive side and locate the sheet guide at the operator side of the rolls (Figure 5.46).

(b) *Duplex Mill.* Two cantilever mills facing each other, forming both edges of the strip simultaneously are called a duplex mill (Figure 5.47). Adjusting one or both mills in-and-out enables the forming of an infinitive number of widths within the limits of the mill. The roll designer should take the following into consideration:

- Maximum roll length is limited.
- The forming pressure at the end of the rolls (away from the bearings) may bend the shafts
- The material for forming should be taken from the drive side only (material cannot be taken for the strip center, or in other words, the guide plane must be at the center of the strip).
- For wider sections, supports are required between the rolls, both underneath and above the strip (Figure 5.48a,b). A section is considered to be wide when the width:thickness ratio is over 60 to 140 (depending on the yield strength of the material and other factors).
- To eliminate marks on the product, the end of the rolls shall not have sharp corners (Figure 5.49a,b).
- Asymmetrical forming may drive one edge faster than the other. Proper guidance in the mill as well as at entry and exit is required.
- Proper guidance as well as additional devices may be required when short precut sections are formed. Under normal conditions, the minimum product length should not be less than twice the horizontal roll distance plus 1 to 2 in. (25 to 50 mm). This will ensure that the product is engaged in at least in two passes at each side, at any time.
- If the width and the length dimensions of the precut blanks are similar, or the length is shorter than the width, then special devices will be required to avoid “skewing.” One side driving faster than the other may cause jamming and stop the product in the mill.
- In the case of asymmetrical forming, fully formed angles will provide better guidance than partially formed ones (Figure 5.50) because it is more difficult to guide an edge formed at 10 to 15 to 20° than the one formed at 90°.

TABLE 5.1

DELTA ENGINEERING INC.	**INFORMATION FOR DESIGN & SUPPLY OF ROLLS**		No. Page of
Customer:			Date :
Product:			
The following information is required and/or will be helpful to design rolls: 1. **MILL**	Information Needed to Suit Specific Mill	Helps to Know	No Spec
1.1 Make, Type		☒	☐
1.2 Shaft Diameter	☒		☐
1.3 Key Size	☒		☐
1.4 Maximum Roll Space	☒		☐
1.5 Pass Line Above Center of Bottom Shaft	☒		☐
1.6 Clearance Below Center of Bottom Shaft	☒		☐
1.7 Max. Vertical Center Distance Between Shafts	☒		☐
1.8 Min. Vertical Center Distance Between Shafts	☒		☐
1.9 Horizontal Center Distance Between Shafts		☒	☐
1.10 RPM Ratio Between Top & Bottom Shafts	☒ 1:1 ☐ or ☐		☐
1.11 Number of Available Passes	☒		☐
1.12 Will Product Straightener Be Used ?		Yes ☐ No ☐	☐
1.13 Is Entry Guide Available?		Yes ☐ No ☐	☐
1.14 Is Coolant / Lubricant Applied?		Yes ☐ No ☐	☐
1.15 Is any other process incorporated in the line? (If yes, provide information)		Yes ☐ No ☐	☐
1.16 Direction of Line (flow of material viewed from operator side)	From Left to Right ☐ From Right to Left ☐	Note: For other equipment in the line, see other Tables	
2. **ROLLS**	PROVIDE INFORMATION IF AVAILABLE		NO SPEC
2.1 Material (Type)	☐		☐
2.2 Is Splitting required (if Yes, provide details)	☐		☐
2.3 Is Side-Roll recommended	☐		☐
2.4 Is Side-Roll prohibited (space)	☐		☐
3. **MATERIAL TO BE FORMED**	INFO NEEDED	INFO USEFUL	
3.1 Material Type, Physical Properties	☒		
3.2 Coating (Type, Thickness)	☒		
3.3 Nominal Thickness "t"		☒ t =	
3.4 Max. Thickness "t" (incl. +Tolerance & Coating)	☒ t =		
3.5 Minimum Thickness (at minus -Tolerance)	☒ t =		
3.6 Blank (Width) Tolerance ± .005 ☐	or :		
3.7 Continuous Feed (Coil, Strip) Yes ☐	or Sheet ☐		
3.8 If product is pre-cut, provide Length(s) :			
3.9 Additional information on Material :			

(*Continued*)

TABLE 5.1 Continued

DELTA ENGINEERING INC.	**INFORMATION** **FOR** **DESIGN & SUPPLY OF ROLLS**	No. Page of
Customer:		Date :
Product:		

4. **PRODUCT**

DRAWING NO.	REV. NO.	DATE OF LAST REVISION

4.1 Product Drawing(s) attached :
Note: Specify all Tolerances on drawings
4.2 Are cut-outs, notches, embossing etc. on
product before roll forming …………………………… Yes ☐ No ☐
4.3 Is orientation of product specified
(Position of shape at last pass) ……………………….. Yes ☐ No ☐
If Yes, e.g. for other in-line process or inspection,
please indicate it on drawing, mark also painted side etc.
4.4 Application of the product :

5. **ROLL DRAWING AND OTHER REQUIREMENTS**

5.1 Set Up Drawings supplied …………………………… Yes ☐ No ☐
5.2 Additional Drawings required …………….. Flower Diagram ☐ Roll Drawings ☐

Note: Normally one set of drawing is supplied
Additional sets of roll drawings or flower diagrams are available at extra charge

6. **ADDITIONAL COMMENTS** NONE { Additional sheet(s) with comments attached {

Form Completed By : (print name) ___________________________ **Date:** ________________________

Contact Name (if different from above) : ____________________

TEL : _____________________________ **FAX :** _____________________ **Email:** ___________________

Address : ____

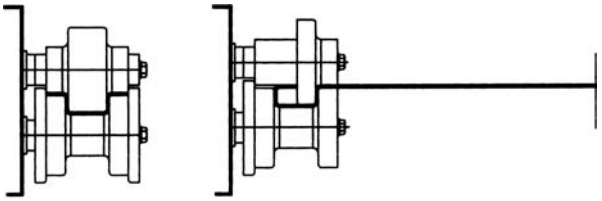

(a) section roll forming
(b) edge roll forming

FIGURE 5.46 Forming narrow and wide section in a cantilever mill.

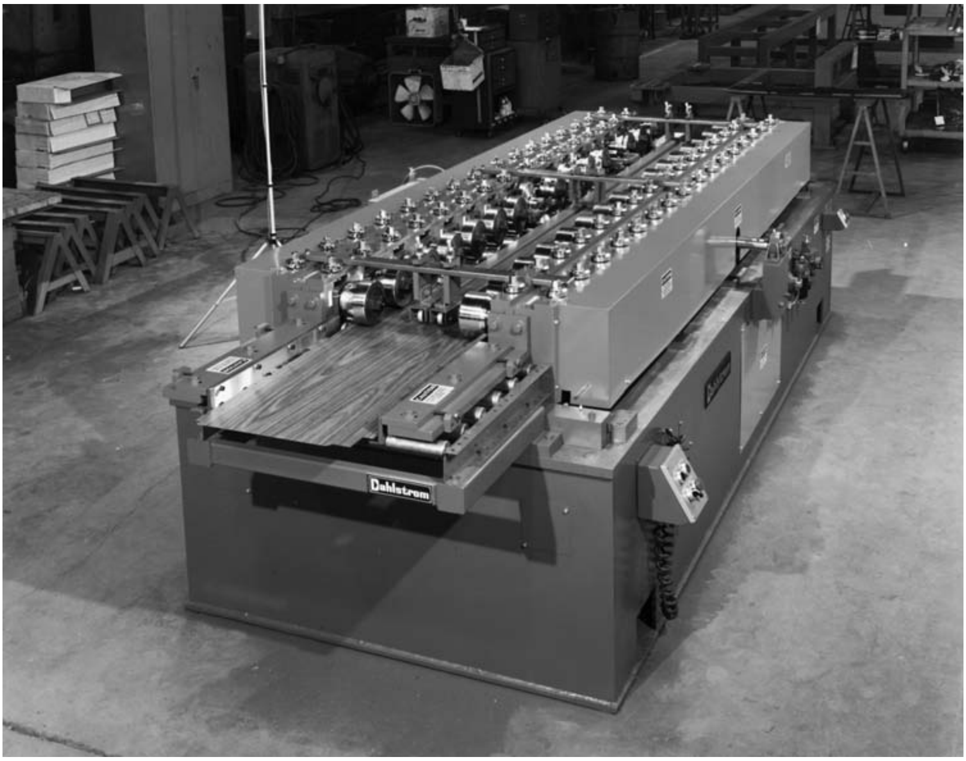


FIGURE 5.47 Duplex mill. (Courtesy of Dahlstrom Industries.)

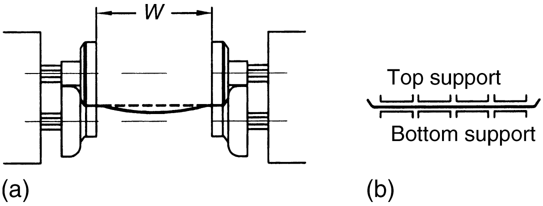


FIGURE 5.48 In wide duplex mills ($W = 75$ to 200 t), supports are required at the bottom and top of the strip.

- In more complex cases, short precut blanks are guided through the mill with special devices, chains, and so on (Figure 4.50).
- Long entry and exit guides are recommended especially for precut sections. Guides for precut sections should be longer than the width of the blank, and also at least 3 to 4 times the horizontal distance between passes.
- The horizontal center of most duplex mills is short. The little space left between the rolls makes the installation and adjustment of side-rolls or guides difficult.

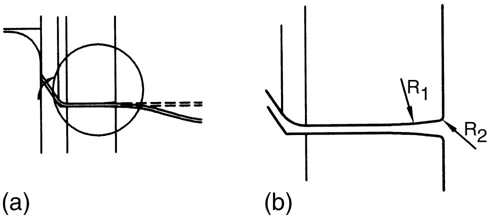
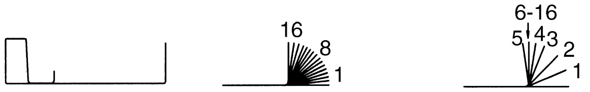


FIGURE 5.49 Large radius at the end of the cantilevered rolls will eliminate marks.



(a) Finished section (b) Traditional forming of right edge (c) Recommended forming

FIGURE 5.50 Forming of asymmetrical sections require better guides than a symmetrical one.

- The roll design, including the bolts holding the rolls can determine the narrowest product that can be made on the mill.
- Bottom and top hold-down devices may have to be made easily removable or adjustable to suit different widths.
- Sometimes, it is awkward to check the shaft shoulder alignment in cantilever mills, and the alignment and parallelness in duplex mills. The alignment can be made easier and be checked much quicker with a straight edge if the roll designer specifies that the length of all rolls should be kept within ± 0.0005 in. (0.013 mm).

(c) *Duplex Through Shaft Mills*. Through shaft mills, depending on the roll and shaft lengths (Figure 5.51), can have 25 to 60% less deflection (or in other words, 25 to 60% higher load capacity) than the cantilever mill with the same shaft diameter and roll length.

In these mills, the drive-side rolls are attached to the drive-side stands and the operator-side rolls to the operator-side stands (Figure 5.52). The rolls are locked on sleeves which rotate with the shaft but allow movement along the axis of the shafts when the stands are moved in or out.

Most items that have to be considered when designing rolls for duplex mills also have to be taken into consideration for the duplex through shaft mills. The difference is that due to the added sleeves, the roll diameters of the through shaft mill will be larger and the horizontal centers are usually greater. Adjustable center-support rolls for the product can be installed on the shafts.

(d) *Standard Mills (Shafts Supported at Both Ends)*. The majority of roll forming mills have the shafts supported by bearings at both ends (Figure 5.53). Most of the previously mentioned factors and several others have to be considered for standard mills.

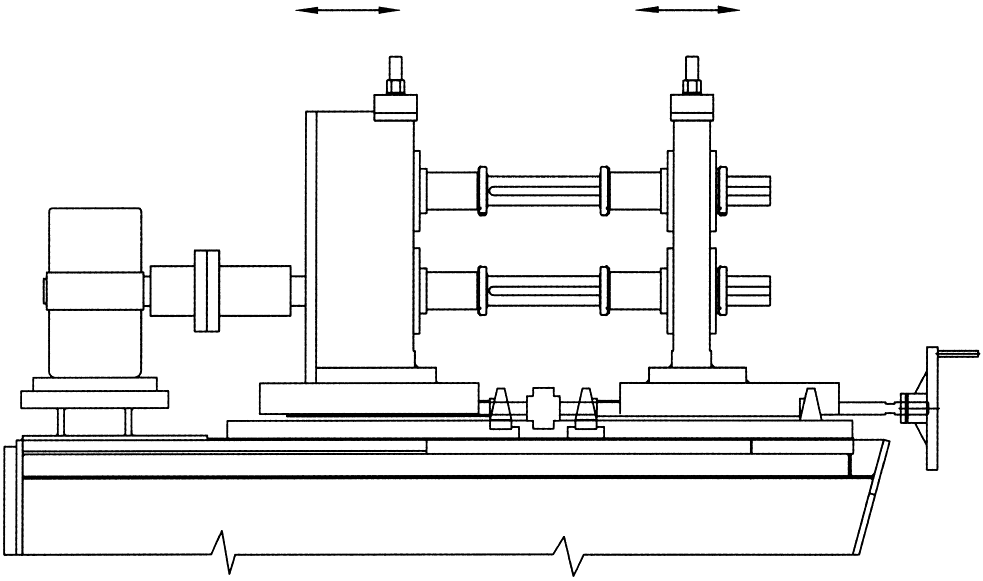


FIGURE 5.51 Through shaft duplex mill.

5.5.3 Shaft Diameter

The shaft diameter is established by the mill manufacturer, taking the maximum thickness, maximum strength and the maximum width of the material into consideration. It is the roll designer's responsibility to point out before roll design starts if in his/her opinion the shaft diameter of the mill is not sufficient to form the product.

The "makeshift" arrangements to support insufficient diameter bottom shafts or top shafts with rolls or applying a yoke to hold the top and bottom shaft between stands together are not recommended. This "emergency" measure makes mill adjustment and roll changes very difficult and it should be avoided.

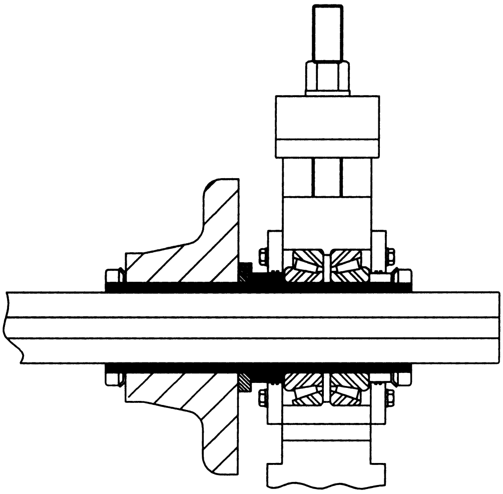


FIGURE 5.52 In through shaft mills, the roll supporting sleeves are attached to the stands.

5.5.4 Horizontal Distance

Horizontal distance is the dimension from the shaft center to shaft center in the horizontal direction (see "HD" in Figure 5.54). This pass-to-pass distance is critical when forming the following products:

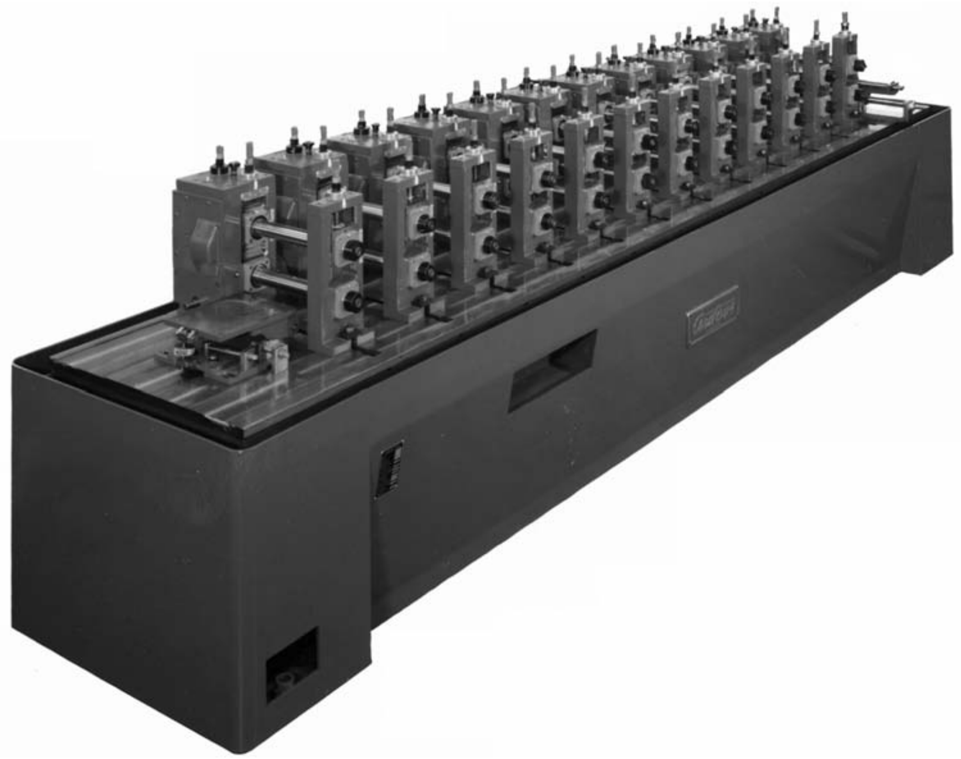
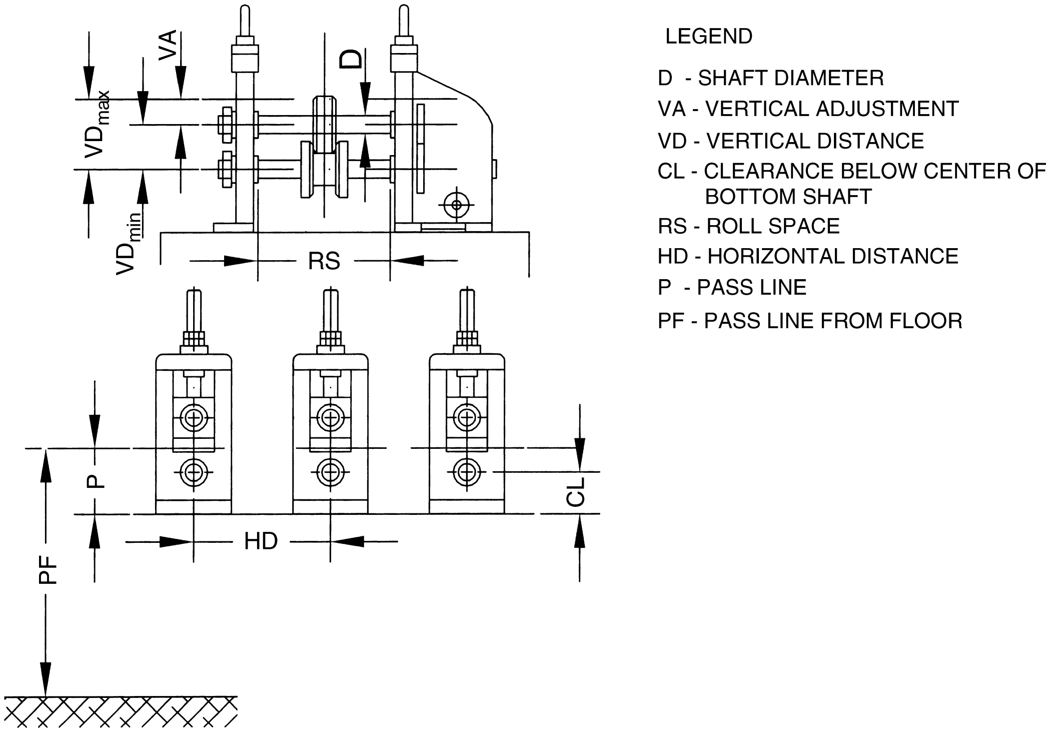


FIGURE 5.53 In "standard" mills, the shafts are supported at both ends. (Courtesy of Ardcor.)



LEGEND

D - SHAFT DIAMETER
VA - VERTICAL ADJUSTMENT
VD - VERTICAL DISTANCE
CL - CLEARANCE BELOW CENTER OF BOTTOM SHAFT
RS - ROLL SPACE
HD - HORIZONTAL DISTANCE
P - PASS LINE
PF - PASS LINE FROM FLOOR

FIGURE 5.54 Mill dimensions must be considered during roll design.

(a) *Wide Panels.* The bend line not only moves upwards, but the edges and a wide flat segment of the coil move inwards (Figure 5.11a). If the space between the stands is not sufficiently long, then the product will be wavy and distorted.

Example

A set of rolls produces good-quality wall panels in a mill with a 24-in. (610-mm) horizontal distance. The same set of rolls is placed on another mill which has the same number of passes, same shaft diameter, same roll space and same top-to-bottom shaft rpm ratio, but the horizontal center is shorter (e.g., 21 or 18 in., or 530 to 460 mm). It is conceivable that the same rolls will not form acceptable quality panels, especially from lighter gauges in the mills with shorter center distance.

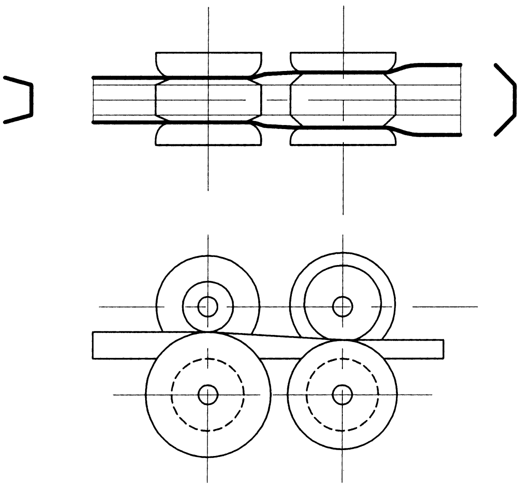
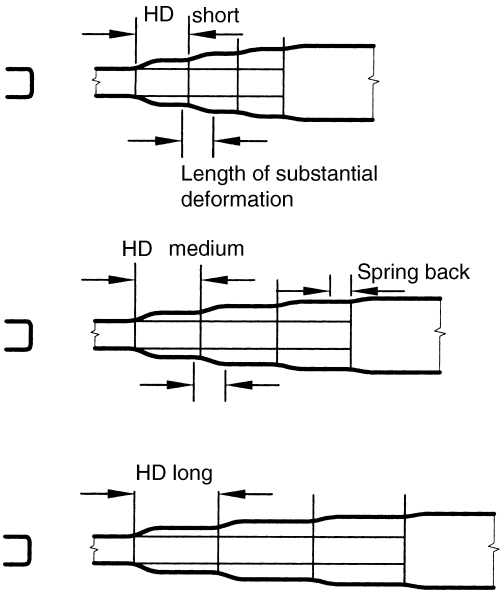


FIGURE 5.55 Roll forming deep section in a mill with short horizontal center will generate undue high stresses.

(b) *Deep Sections.* Deep sections, particularly those made from thick or high strength material, require sufficient horizontal center so they can be formed without undue stresses. The deeper the section, the larger diameter the forming rolls will be. The larger the rolls are, the larger the horizontal centers should be (Figure 5.55). Too-short horizontal distance will create flare, waviness, and other deviations from straightness and flatness.



Example

It is planned to roll form 6-in. (ca. 150-mm) deep sections from 0.375-in. (9.5-mm) thick material in a mill with 5-in. (125-mm) diameter shafts. The company has three mills, one with 24-in. (610-mm), one with 36-in. (915-mm), and one with 48-in. (1220-mm) horizontal centers.

The minimum roll diameter is assumed to be 8 in. (203 mm), and the maximum roll diameter will be twice the section depth plus lead-in length, say, 24.5 in. (622 mm). The mill with the 24-in. horizontal center cannot be considered because the rolls will not fit on that mill. The mill with 36-in. (915-mm) horizontal center will provide a mere 9-in. (229-mm) space between rolls while the 48 in. (1220 mm) mill will have 23-in. (585-mm) space between the rolls. The 36-in. (915-mm) center distance will allow only limited forming; therefore, more passes are required. The space between the rolls is not sufficient to install and adjust suitable size side-rolls. Therefore, the best mill on which to form the section is that with 48-in. (1220-mm) horizontal center distance.

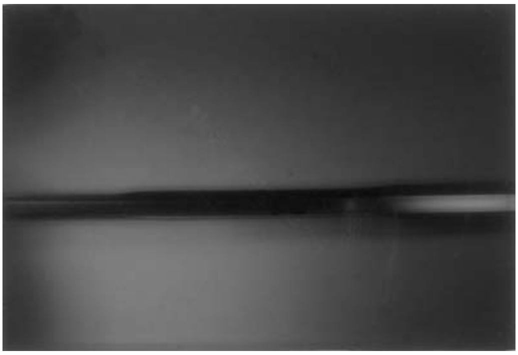


FIGURE 5.56 The horizontal center (HD) may not be important when shallow sections are roll formed from thin or low strength material.

(c) *Side-Rolls, Guides, and Operator's Convenience.* The horizontal distance is not critical when shallow, small sections are formed (Figure 5.56). In this case, deformation is restricted to a few inches ahead of the contact points of the rolls. Therefore, whether the horizontal distance is 8, 12, 16, or 20 in. (200, 300, 400, or 500 mm) will have no influence on the roll design.

However, in some roll forming mills, especially those designed to form short precut sections, the rolls are so close that it is difficult, if not impossible, to install and adjust the side-rolls or other units. Side-roll stands are occasionally installed at the "empty" roll stands which do not have main rolls or are mounted on the stands. Nevertheless, tight space can make setup and checking of the roll gaps with feeler gauges extremely difficult.

(d) *Short Precut Pieces.* To guide a short piece through the mill, the minimum length of the part should be a little bit more than twice the horizontal center distance (HD; Figure 5.57). For example, if the HD of a mill is 8 in. (200 mm), then the shortest precut piece should be at least $2 \times 8 + 1 = 17$ in. (425 mm), assuming that the part length is at least double of the blank (strip) width (see also Section 5.5.2b).

5.5.5 Vertical Distance

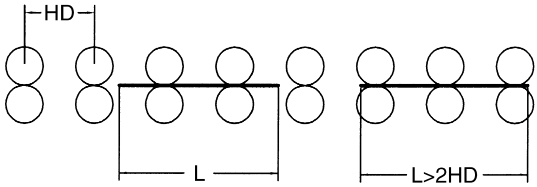


FIGURE 5.57 The length of a precut piece should be more than twice the horizontal distance between passes.

The vertical distance (VD) of Figure 5.54 is the maximum distance between the center of the top and bottom shafts. The vertical distance is usually adjustable and if so should be expressed with the minimum and maximum values. A minimum vertical distance is required to accommodate the top and bottom rolls and the section in between them. Figure 5.58 shows two sections. The maximum height of the section to be considered as the limiting factor is not necessarily the finished section, and it can be at one of the previous passes.

The maximum and minimum distances shown in the equipment sales literature are occasionally not accurate. When the vertical distance will be close to the maximum or minimum, it is advisable to check the actual maximum and minimum vertical distances of the equipment before roll design commences. When the designer opts for the minimum vertical distance (the smallest possible roll diameter) for economical reason, then some "extra" should always be added to the roll diameters as a "safety" factor and for future recuts.

It is not always necessary to have the same vertical centers at all passes of the mill. Increasing the vertical centers as the section grows in height is quite common.

In the case of being in a predicament, the vertical distance may be increased by placing spacers between the stands and the horizontal cross-bars as shown in Figure 5.59. The thickness of the special spacers is limited by the size of the stand, engagement of the bearing blocks, and the method of driving the top shaft. Link types of gear head may not be suitable for this solution unless the top drive is disconnected.

5.5.6 Distance between the Bottom Shaft and Mill Base

In most (although not all) mills, the bottom shaft is in a fixed position and is not adjustable. The distance between the center of the shaft and the mill base (or the highest point anywhere underneath the shaft) constrains the maximum bottom roll diameter. In spite of such a clear-cut and simple fact, many designers made the mistake of specifying rolls with larger diameter than the space available for installation (Figure 5.60).

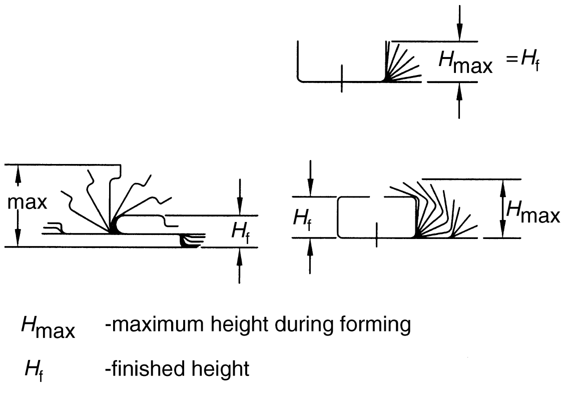


FIGURE 5.58 Maximum section height (H_{max}) must fit between rolls.

5.5.7 Key Sizes and Keyways

The key sizes vary from mill to mill, and from roll set to roll set due to the lack of any standard.

The key size is a function of the transmitted torque while the shaft diameters are designed for deflection. However, key sizes can be standardized to suit shaft diameters.

Delta's "Roll Former's Guide©" software uses Equation 5.2 to calculate key sizes. The calculated size has to be rounded (usually up) to the next standard key size.

$$\begin{aligned} &\text{(imperial) } W_{\text{inch}} \\ &\quad = 0.11d^{0.65} + 0.002(D_{\max}^{1.43}) + t^{0.51} \\ &\text{(metric) } W_{\text{mm}} \\ &\quad = 0.34d^{0.65} + 0.000506(D_{\max}^{1.43}) + 4.8t^{0.51} \end{aligned} \tag{5.2}$$

where

W = key width
d = shaft diameter
$D_{\max}$ = largest roll diameter
t = metal thickness
k = key height (frequently equal to W)

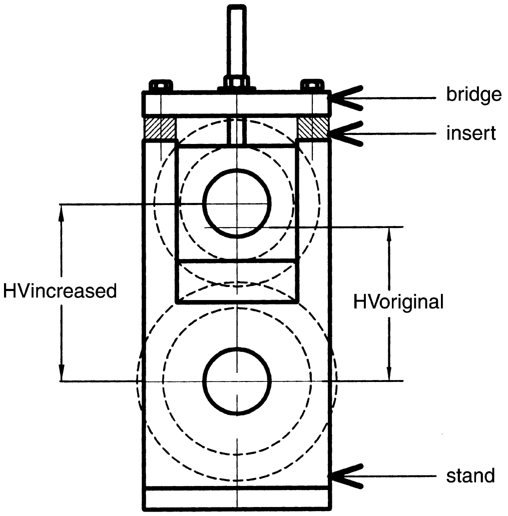


FIGURE 5.59 Vertical height (HV) can be increased in certain mills.

The roll designer should incorporate matching keyways into all rolls and spacers, except the shoulder alignment spacers. The gap between the key and keyway in the rolls and spacers ("b" dimension) should be sufficiently large to assure easy installation and removal of the rolls.

Keyway width in rolls = key width + b

Keyway depth in rolls
= one half of key height + b or $2b$

For recommended "b" dimensions in small and medium size rolls see Table 5.2.

For large diameter rolls, the key sizes must be increased because the inertia of 10- to 20-in. (250 to 500-mm) diameter rolls will destroy small keyways in the shafts if the mill is frequently and quickly stopped and started.

In these large diameter rolls, the keyway should be only slightly wider than the key (b = 0.005 to 0.010 in. = 0.13 to 0.25 mm).

The "b" clearance also depends on the accuracy of the key cutting equipment.

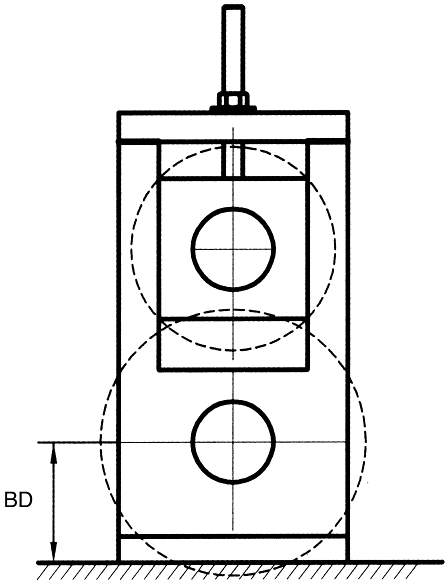


FIGURE 5.60 Maximum bottom roll diameter is restricted by the distance between the bottom shaft and mill base and other protrusions.

5.5.8 Top Shaft Drive

The roll designer must know if only a selected number of top shafts are driven. Driven top shafts, with added friction, provide a better strip "pull" from the uncoiler and more even speed.

TABLE 5.2 Keyway Width in Rolls

Key Width	*b*
3/16 to 1/2 in. (5 to 12.5 mm)	1/16 in. (1.5 mm)
Over 0.5 in. (12.5 mm)	1/8 (3 mm)

Nondriven top shafts are less expensive, but the mill may not have sufficient friction to pull the material when only the first few passes are engaged. Mills with bottom-driven-only last passes may not generate sufficient "pull" (tension) to avoid buckling between the passes and to push the material through the straightener or curving unit and the cutoff die.

For mills with partial spur-gear drives at selected locations, the roll designer must specify the passes which require top shaft drive. Usually, at least the first two and the last two passes are driven. Depending on the circumstances, additional passes could also have top drives. If a spur-gear on the bottom roll directly drives a spur-gear installed on the top roll (or vice versa), then the gear pitch diameters will also determine the pitch diameters of the rolls. The roll pitch diameter must match the gear pitch diameter with allowance to adjust for material thickness variation and limited recuts of the rolls.

Roll forming mills with the facility for quick disconnection of the top roll drive are the most versatile for selecting the appropriate top shafts to be driven.

In deep sections, the surface speed differential between different parts of the rolls and the material can be large. To minimize the friction, not only the top shaft is nondriven, but individual segments of the rolls are occasionally allowed to run free on bearings installed on the shafts (Figure 5.61). The reduced friction will reduce tool wear, horsepower requirement and surface scratches. It is the tool designer's function to determine which rolls should be free-running. The roll designer also has to cooperate with the machine designer to ensure that the bearings of the free-running rolls can be properly lubricated.

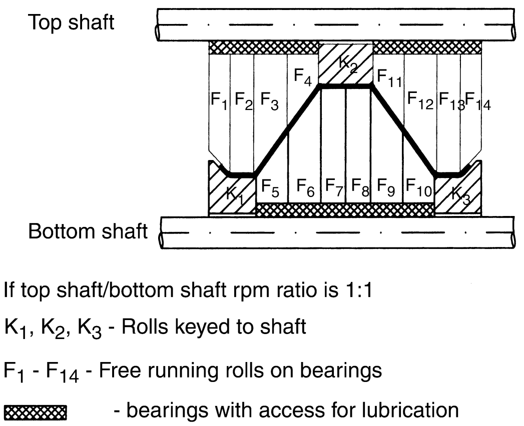

Top shaft
F1
F2
F3
F4
K2
F11
F12
F13
F14
K1
F5
F6
F7
F8
F9
F10
K3
Bottom shaft
If top shaft/bottom shaft rpm ratio is 1:1
K1, K2, K3 - Rolls keyed to shaft
F1 - F14 - Free running rolls on bearings
▨ - bearings with access for lubrication

FIGURE 5.61 "Free-running" rolls reduce friction between rolls and formed sections.

5.5.9 Bottom Shaft Drive

It is accepted by the roll forming industry that, as a rule, all bottom shafts are driven. However, occasionally not driving some bottom shafts has advantages.

Example

A bottom-driven mill, with a few top-driven passes, forms a building panel with seven ribs (Figure 5.62). The forming starts by making the center ribs in five passes. Forming continues with the adjacent two ribs, made in the next five passes, then the next two ribs in five passes, and, finally, the two outside ribs in six passes. As the rib heights are gradually formed to full height, the diameter of the driven bottom rolls increases. If the section depth is 1 in. (25.4 mm), then the circumference of the larger rolls is about 6 in. (152 mm) larger than the rolls that start to form the ribs. Because the shafts are running at the same rpm, the last few rolls forming each rib are "pulling" the material faster then the first two rolls. Actual observation showed that passes 1 and 2, 6 and 7, 11 and 12, and 16 and 17 (circled in Figure 5.62), which start to form the ribs, have negative torque, or in other words, are breaking, pulling back the formed section. The first two passes cannot be disconnected because they are required to pull the front end of

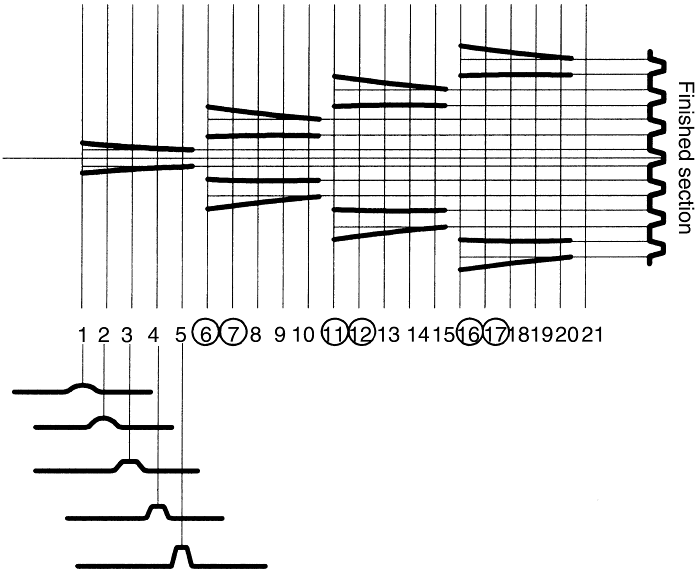


FIGURE 5.62 A 7-rib panel roll formed in 21 passes (schematic representation).

each coil into the mill, but disconnecting the other 6 passes (6, 7, 11, 12, 16, and 17) would reduce the energy required to form the panel, would reduce tool wear and surface marks. It would also provide less fluctuation in the panel speed, which would improve length tolerance. Unfortunately, the construction of most mills does not allow observing the negative torque (braking) without instrumentation. (Note that the actual forming was different then described above; the forming sequence has been simplified for this example.)

5.5.10 Rpm Ratio

To establish the roll diameter, the roll designer must know the rpm ratio between the top and bottom shafts. A ratio is usually given by the manufacturer as 1:1, 1:1.33, 1:1.42 or other figures that are based on the gear ratio of the drive. The above-mentioned figures mean that the bottom shaft runs at the same rpm, or 1.33 or 1.42 times faster then the top shaft. Therefore, the bottom roll diameter can be 1.33 or 1.42 times smaller than the top diameter. This arrangement is economical for "U" channels and for similar sections formed with legs up, but it is not economical, and in most cases not suitable for sections with legs down.

The roll designer must also check the means provided to quickly disconnect the top rolls and the necessity to apply drive to the top rolls or to use free running rolls.

5.5.11 Pass Line Height

Pass line is the distance between the mill bed and the bottom of the section at the last pass, at the point where the surface speeds of the top and bottom rolls are equal (Figure 5.63). It is prudent to have the pass line height for each mill established (standardized) by the plant management. If possible, all the sections formed in mill should have the same pass line height. This will eliminate the time-consuming adjustments of the entry guides and the straightener height, and costly cutoff press height adjustments. Once the pass line and the cutoff press heights are established, the press position need never be adjusted.

The pass line height specified by the management should be checked by the roll designer to ensure that it does not interfere with good forming practice. Owing to the small increase in roll diameters from pass to pass, the pass line is most frequently not parallel to the mill bed as explained in Section 5.6.4d.

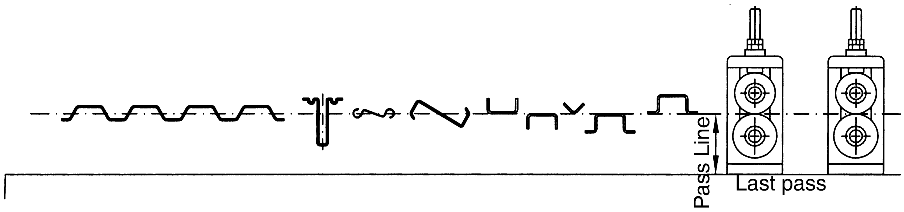


FIGURE 5.63 Pass line height above the mill bed is where the surface speeds of the top and bottom rolls are equal.

5.5.12 Additional Items

The roll designer must know whether entry guide, straightener, lubrication, and other critical items are available on the mill.

5.5.13 Direction of the Line

The direction of the line (left to right, or right to left) is important as it determines the operator side of the mill.

5.5.14 Motor and Roll Forming Speed

It should be discussed before roll design commences if, in the opinion of the roll designer, the specified horsepower appears to be insufficient or if the line speed is not correct.

The calculated speed is always an estimate. The actual speed will be influenced by the speed differential between the rolls and the strip, friction modulus (lubricant), setup (pressures), and other factors.

5.5.15 Available Number of Passes

The roll designer must check whether the estimated number of passes required to form a section is available in the mill. If there are not enough passes, then the design may have to be different and more side-roll passes have to be incorporated, or additional passes have to be added to the mill. If these improvements are not feasible, then the design assignment may have to be declined. One of the most common mistakes made by roll designers is trying to form the product with fewer passes than required for good forming simply to match the available number of pass on the mill. Sometimes, the designer does not have any other alternatives, but this approach frequently leads to inferior product quality, productivity problems, or completely discarded tooling.

5.6 Other Tool Design Considerations

5.6.1 Roll Change Requirements

Rolls have to be removed and reinstalled on the mill shafts frequently or occasionally, but at least once in every six months. The type of the mill and the frequency and method of roll changing have a profound influence on roll design.

(a) *Duplex Mills.* In most duplex mills, the rolls are held in their position by a bolt threaded into the center of the shaft. The majority of the duplex mills are dedicated lines and do not require roll changes. Therefore, the interchangeability of rolls is seldom considered during roll design.

(b) *Standard Mills.* Roll sets are designed for specific profiles. When the profile is changed, the complete set of rolls is removed and replaced with the rolls for the new profile. Multipurpose rolls, usually employed for the same profile formed in different widths, are changed by partially removing and exchanging the sequence of rolls or spacers. Where quick-change spacers are used the rolls can be moved sideways on the shafts without removing them.

(c) *Rafted Mills.* The rafts are usually dedicated for a single profile. Therefore, roll change is not a serious design consideration. However, occasional removal of the rolls (say, once in every 6 months) is still recommended to prevent the "seizing" of the rolls on the shafts by rust, loose particles, or aged lubricant.

5.6.2 Splitting Rolls

Rolls are split into smaller lengths for several reasons.

(a) *Roll Weight.* The price of a roll set is related to both the number of rolls and the weight. The weight of a set of rolls can seldom be reduced but designers often attempt to reduce the price by making the longest thus the least number of rolls. However, roll lengths are also influenced by other factors.

One consideration is the weight of a single roll. It is difficult to install and remove rolls weighing over 50 to 70 lb (22 to 31 kg). At some companies, an even lower safe lifting weight is specified by safety standards, regulatory bodies, or union agreement. However, to fully conform to the weight limit, large diameter rolls would yield rolls so short (thin) that they would be distorted during heat treatment. The weight of large diameter and dimensionally stable rolls can be considerably above the safe weight limit. In this case, as well as speeding up roll change, it is sensible to consider mechanized roll unloading/loading.

(b) *Mechanical Installation/Removal.* After the removal of the outboard stand, one method is to place "dummy" shafts to the end of the mill shafts and slide the rolls from the mill shaft to the dummy shaft. The dummy shaft has to be mechanically held in position and lifted. It is the roll designer's responsibility to point out to the customer if the roll weights are over the safe lifting limit.

(c) *Length Limitations.* Even if weight is not a restricting factor, rolls are seldom made longer than 6 in. (150 mm). The gap between the shaft and bore of the rolls is so small that the smallest bend in the shaft will make it difficult or impossible to install or remove the rolls. To minimize this problem, it is a common practice to relieve the center part of the bore of rolls longer than 2.5 to 3.5 in. (65 to 90 mm; for further details, see Figure 5.64). If the bore is so relieved, then it is important to check the load on the remaining contact surface with the shaft. Too short a roll/shaft contact area can damage the surface of the shaft.

Rolls that are too short (thin) result in other problems. First of all, it is difficult to keep thin rolls flat during heat treatment. The second difficulty installing them on or removing them from the shafts. Thin rolls can easily jam on the shafts. To avoid jamming, experienced operators use the next longer roll or spacer to keep the thin rolls perpendicular to the shaft during installation/removal (Figure 5.65). Thin rolls are also more susceptible to cracking or chipping.

(d) *Machinability.* Turning technology and the geometry of the turning tools limit the shape that can be turned. Figure 5.66 shows a typical example when rolls have to be split to facilitate machining.

(e) *Multiple Applications of Rolls.* The location of roll splitting can be dictated by multiple product widths. For example, if "U" channels are formed in 4-, 6-, and 8-in. (100-, 150-, and 200-mm)

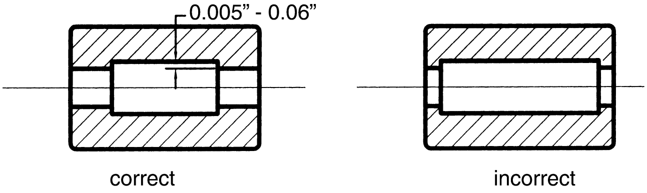


FIGURE 5.64 The bore of long rolls is relieved to ease installation.

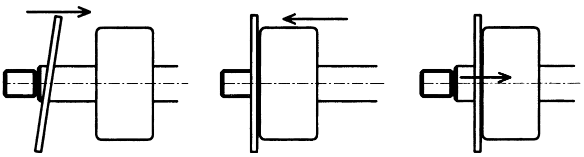


FIGURE 5.65 It is easier to install short rolls with the help of a longer one.

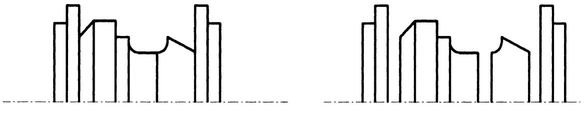


FIGURE 5.66 Restrictions in machining can dictate the locations of splitting.

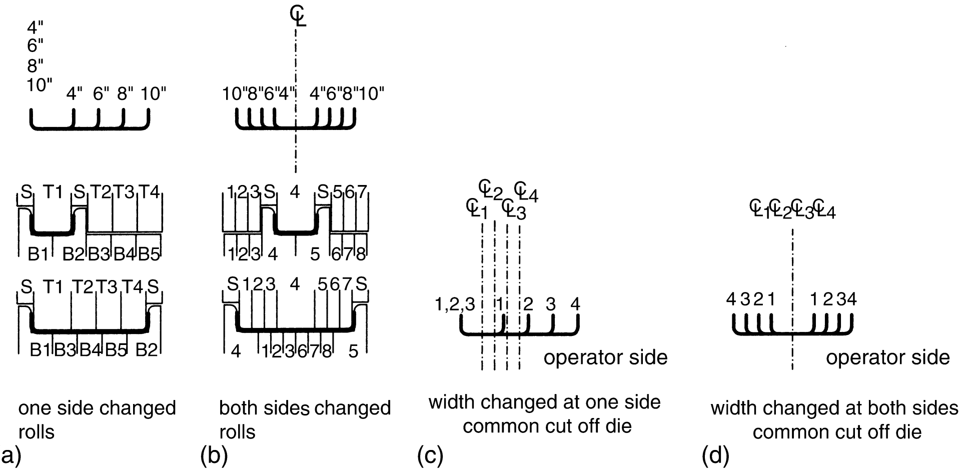


FIGURE 5.67 Product width can be changed by changing rolls and spacers (a and b); cut-die die should match the method of width change (c and d).

widths, then the lengths of the split roll should have 2-in. (50-mm) increments. The location of splits of rolls used for multiple widths will also depend on the method of roll change. The width change can be made at one side only, or by keeping the center line constant and changing both sides (Figure 5.67).

5.6.2.1 Interchangeable Rolls

Rolls are always designed to suit specific products within given conditions. However, for economical reasons, it can be advantageous to use the same rolls for multiple purposes, if conditions and roll design are right.

Example 1

Custom roll formers have large number of rolls in stock. They try to utilize the existing rolls for different profiles rather than making new rolls. Most frequent application is the use of flat or angled rolls for a variety of "U," "C," "Z" channels and other sections with different dimensions. These "multipurpose rolls" may represent 10, 20, 50, or even 100% of the total number of required rolls.

Example 2

Similar profiles have to be formed with 65 and 75° angles. Instead of making two sets of female rolls for the drive and operator side, the same female rolls can be used for both the 60 and 65° products. One side of the "common roll" has 60°, the other side 65° angles (Figure 5.68). To change to the other product, the operator has to "flip over" these two multipurpose female rolls. The male rolls, designed for the 65° product are not changed.

The same solution can be used when roll forming "soft" material with a 1° overbend and a "hard" material with, say, 6° overbend to compensate for the different springbacks.

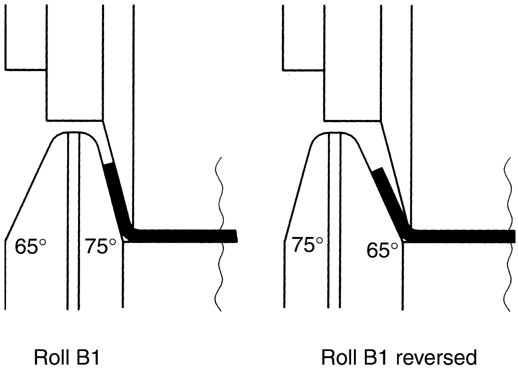


FIGURE 5.68 Double-faced roll can form two different bending angles when flipped around (from outside to inside).

(f) *Changing Width at One Side Only.* When product change is performed by changing rolls at the operator side only, the drive side-rolls are not moved (see Figure 5.67a). The operator side rolls are pulled off and rolls from the outside are placed inside and vice versa. The center line of the profile moves accordingly closer to the operator.

(g) *Changing Width at Both Sides.* In this case, the center line remains at the same position. The change of both sides is more cumbersome, it is applied when the center line must stay in position in spite of the additional cost and changing time. This is often the case when holes are prepunched on or symmetrical to the center line. Because the drive side rolls are also changed, usually all the rolls have to be removed from the shaft (Figure 5.67b).

If the product is cut to length after roll forming, then it is important to co-ordinate the roll design with the cutoff die design (Figure 5.67c,d). This rule is also applicable to duplex mills. Many mistakes have been made by overlooking this simple rule of designing rolls for changing them at one-side while making cutoff dies for both side change and vise versa.

(h) *Minimizing Roll Edge Chipping.* To minimize damage to sharp roll edges during forming, roll change, or storage, as well as for reason of safety, it is important that splitting should not create sharp roll edges (see Figure 5.69).

(i) *Concealing Split Lines.* Owing to manufacturing inaccuracies and distortion during heat treatment, the split line between rolls will be frequently visible on the product. A small radius on the roll edge at the split point helps to minimize or eliminate the marks.

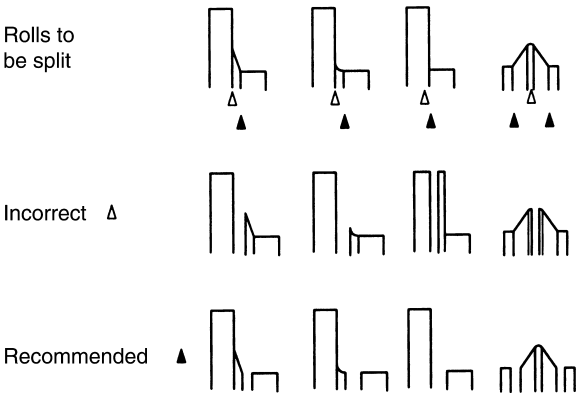


FIGURE 5.69 Avoid sharp edges and too thin rolls when splitting rolls.

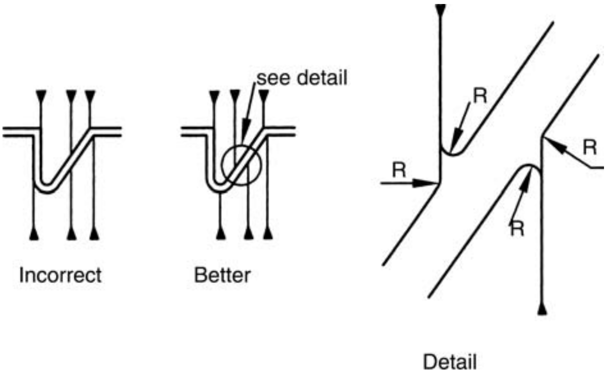


FIGURE 5.70 If splitting rolls at tapered location is unavoidable, then misaligned split lines with generous radii on split lines will minimize roll chipping and the marks on the product.

In many cases, it is better to place the split lines in locations, which in the later passes will become bend lines. In this way, the small marks created by the split lines in the early passes will be concealed by the bend lines at the later passes [581].

Splitting on tapered surface should be avoided wherever possible. However, in the cases of larger rolls, the split may have to be placed on the tapered surface. In this case, attention has to be paid to minimize edge damage of rolls and marks on the product (Figure 5.70).

(j) *Wear.* Excessive wear of certain part of the rolls can be frequently anticipated. For example, grooving (scoring) rolls will wear faster than other rolls. Splitting the grooving roll left and right from the groove will mean that it is only necessary to replace the grooving inserts or it can be made from a more wear resistance material. This type of splitting will also reduce roll reworking cost if for some reason the location of the grooves/scores must be relocated.

(k) *Adjusting Split Rolls with Shims.* The use of shims is not normally recommended, but in special cases, they are required to adjust roll lengths. A typical example is to compensate for thickness changes when the outside dimension of a part is critical (Figure 5.71).

5.6.3 Bolted Rolls

Sometimes, customers are worried about proper setup of rolls by their operators and request to supply split rolls that are bolted together. Occasionally, the roll designer finds it necessary to bolt rolls together

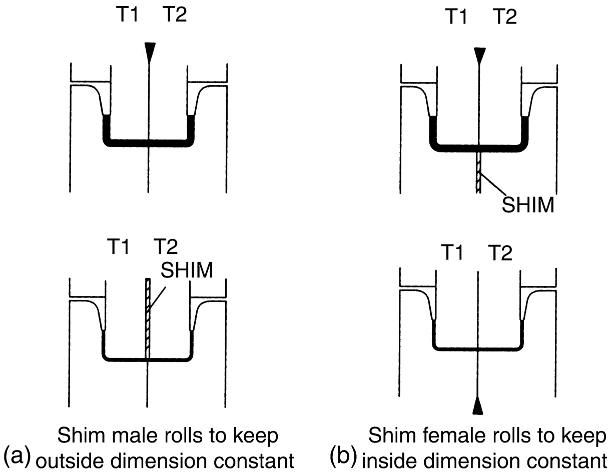
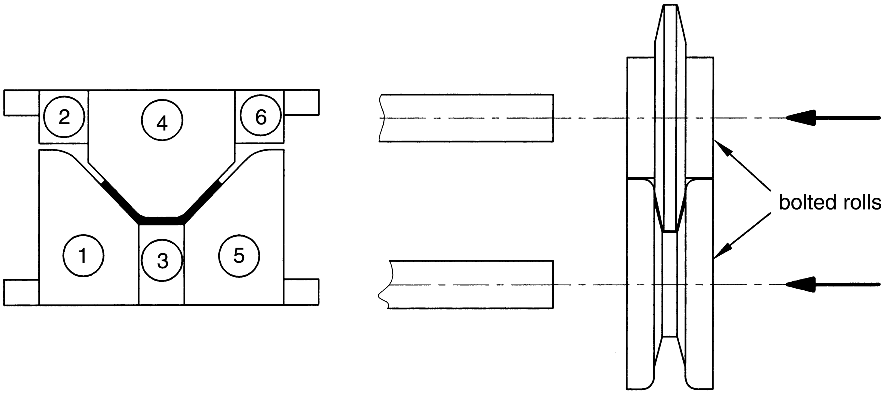

T1 T2
T1 T2
SHIM
T1 T2
SHIM
T1 T2
(a) Shim male rolls to keep outside dimension constant
(b) Shim female rolls to keep inside dimension constant

FIGURE 5.71 Shim placed between split rolls can compensate for thickness changes.



(a) Sequence of placing individual rolls on the shaft (one approach)

(b) Bolted top and bottom rolls are installed on the shaft together

FIGURE 5.72 Sequence of installing rolls is dictated by the roll diameter; installing bolted rolls is difficult and unsafe.

either to reduce the trust on the bearings or for some other reason. However, bolting usually makes a simple roll installation into a complicated and possibly less safe one. Figure 5.72a shows the sequence of installing the top and bottom rolls one-by-one. If the rolls are bolted together (Figure 5.72b), then the top and bottom roll assemblies must be placed on the shafts at the same time. This is a difficult and unsafe balancing act, trying to place heavy rolls on both top and bottom shafts at the same time. Furthermore, it is difficult to maintain the concentricity and alignment of the split rolls after heat treatment or replacing any of the rolls. Therefore, it is recommended to avoid bolting the rolls together whenever possible.

5.6.4 Establishing Roll Diameters

(a) *Influencing Factors*. The roll designer has to determine the pitch diameter of both top and bottom rolls, as well as calculate the minimum and maximum roll diameters. The roll diameters are the function of the section depth, shaft diameter, key size, material thickness, specified pass line height, rpm ratio between top and bottom shafts, and the diameter increases from pass to pass. The calculated diameters have to be reviewed and compared with the available vertical distance and adjustment, or gear pitch diameters, future recutting requirements, available roll stock diameters and other operations in the line.

(b) *Roll Surface Speed*. The top and bottom pitch diameters are defined by the equal roll surface speed. If the rpm ratio of the top and bottom shafts is 1:1, then the pitch diameters and the surface speed of the top and bottom rolls will be equal. If the rpm ratio is, say, 1:1.43, then the surface speeds will be equal at the point where the top roll diameter is 1.43 times larger than the bottom roll diameter.

The pass line height of the mill is determined by the uppermost point of the bottom roll pitch diameter (where the surface speed of the top and bottom rolls are equal) at the last pass.

(c) *Section Depth*. The maximum section depth (shown as "*h*" in Figure 5.58) at each pass plus the lead-in addition (if applicable) is one of the factors that determine the roll diameters.

The Roll Former's Guide uses the following equation to calculate the maximum section depth:

$$\text{Depth}_{\text{max}} = \frac{\text{VD} \times \text{Rpm}}{\text{Rpm} + 1} - 0.5d - \text{St} - \text{“Lead in Flange Height”}$$

where

VD = vertical distance
Rpm = Rpm ratio bottom/top
St = Spacer thickness
d = Shaft diameter

(d) *Pass Line Height*. If the pass line height is preestablished, then the pitch diameter at the last pass is already determined. The pitch diameter will be twice the distance from the center of the bottom shaft to the pass line height (Figure 5.63).

Working backwards from pass to pass, the pitch diameter of each previous pass will be smaller by the roll diameter increment.

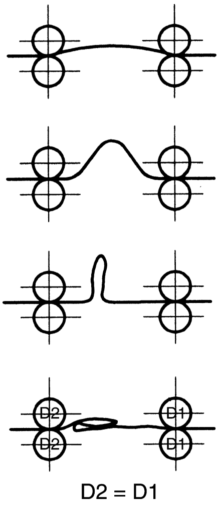


FIGURE 5.73 Strip or product can buckle if it is driven faster by the first rolls than being “pulled” by the subsequent rolls.

(e) *Roll Diameter Increments*. The speed of the strip will depend on the surface speed of the rolls at the pitch (drive) surfaces. The surface speed of the rolls is a function of the roll diameter. If all the rolls have the same pitch diameter, then it can happen that tightly pressed first pairs of rolls may drive the strip slightly faster than it is being pulled by the next rolls. The same problem can happen if the strip speed is reduced by the subsequent passes or by the friction against the straightener, cutoff die, guides, or other in-line operation.. This can create a loop and buckles up the material between passes (Figure 5.73 and Figure 5.74).

To avoid this problem, it is a common practice to keep the strip under tension by gradually increasing the roll diameters, thus the surface speed, from pass to pass (Figure 5.75). A 0.015-in. (0.4-mm) diameter increase means a 0.047-in. (1.2-mm) speed increase. In this case, the 10th pass rolls will have an approximately 0.15-in larger diameter than the first one; thus its surface speed will be 0.5 in. (12 mm) per revolution greater than the speed of the first roll.

The amount of increase of diameter to pass-to-pass is established by the roll designer and usually it is between 0.015 and 0.025 in. (0.4 to 0.6 mm). It has to be noted that in the case of

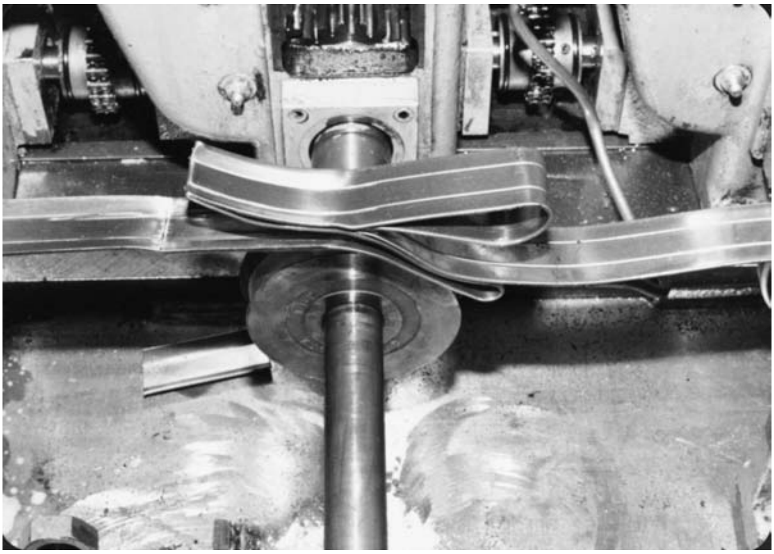


FIGURE 5.74 Multiple layers of parts entering a pass will damage the rolls and bend or break the shafts.

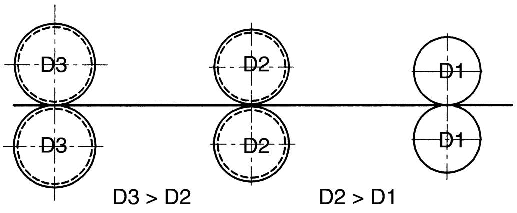


FIGURE 5.75 To avoid buckling, roll diameters are increased from pass to pass.

20 passes and a 0.025-in. increase, the surface speed difference between the first and the 20th pass will be approximately 1.5 in. (33 mm). Too high a speed difference may increase roll wear and may elongate the product. Product length increase can be detrimental if the strip is prepunched. The elongation will not be uniform and it will fluctuate, depending on the pressure created during set up, change in the material thickness, lubrication, bent shafts and other factors. To minimize this problem, designers frequently use diameter increases in the first passes but use the same roll diameters after the product is stiff enough to avoid buckling.

On small mills with short horizontal centers and on wide panel mills, the roll diameters are usually not increased.

(f) *Shaft Diameters, Key Heights, and Material Thickness.* The shaft diameter ("*d*") plus twice the keyway height in the roll ("*k*"; see Section 5.5.7) plus the minimum roll material thickness ("*m*") needed for sufficient roll strength is another factor (Figure 5.76) to be considered by the designer. Equation 5.4 below provides a guideline to calculate the minimum roll diameter.

(g) *Minimum Roll Diameter.* The minimum roll diameter ($D_{\min}$) is a function of the above-mentioned factors (Figure 5.76a):

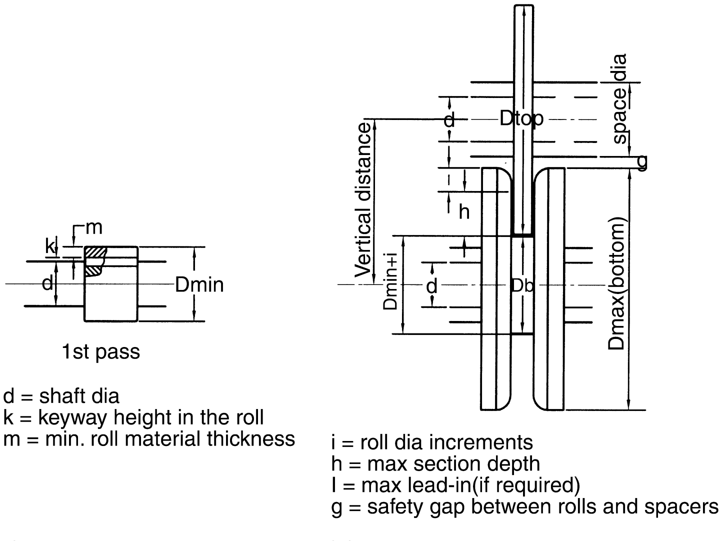
$$D_{\min} = d + 2(k + m) \quad \text{or} \tag{5.3}$$

$$\text{in imperial } D_{\min} = d + 2k + 0.143d^{1.4} \quad \text{or} \tag{5.4 imperial}$$

$$\text{in metric } D_{\min} = d + 2k + 0.265d^{1.07} \tag{5.4 metric}$$

where:

D = roll diameter
d = shaft diameter
k = keyway height in the roll


m
k
d
Dmin
1st pass
d = shaft dia
k = keyway height in the roll
m = min. roll material thickness
Vertical distance
d
Dtop
space dia
g
l
h
Dmin+i
d
Db
Dmax(bottom)
i = roll dia increments
h = max section depth
l = max lead-in(if required)
g = safety gap between rolls and spacers

(a) Minimum Roll Diameter (b) Maximum Roll Diameter

FIGURE 5.76 Minimum and maximum roll diameters.

TABLE 5.3 Minimum Roll Wall Thickness (M) for Forming Mild Steel

Material Thickness	m
Up to 0.075 in. (1.9 mm)	0.3 to 0.4 in. (7.5 to 10 mm)
0.76 to 0.125 in. (1.91 to 3 mm)	0.5 to 0.6 in. (12 to 15 mm)
0.125 to 0.5 in. (3.1 to 12.7 mm)	0.75 to 1.5 in. (20 to 40 mm)

The minimum roll material thickness (m) between the keyway and roll surface is influenced by the thickness and yield strength of the formed material. Table 5.3 provides a guideline for "m" for forming mild steel.

The value of "m" in Table 5.3 may be slightly reduced when roll forming aluminum, but it has to be increased when roll forming stainless steel, high strength, ultra high strength steel or other materials with high yield strength. An increase may also be required when roll pressure is augmented by scoring, stretch grooving or other high pressure operations.

(h) *Maximum Roll Diameter*. The maximum bottom roll diameter is limited by the distance of the bottom shaft center from the mill bed or any other protruding items on the mill bed, which possibly prevents the installation and removal of rolls (Figure 5.60).

$$D_{\max} = 2(V_D - d) - S_t - 0.06V_D^{0.4} \text{ (in inches)} \tag{5.5}$$

where:

V_D = Vertical distance between the shafts
d = Shaft diameter
S_t = Spacer wall thickness

The maximum top roll diameter (Figure 5.76b) is usually restricted by the vertical distance and the vertical adjustability of the top shaft (Figure 5.54). However, the maximum vertical distance and the maximum roll diameter may be increased by the application of stand spacers described in Section 5.5.5.

5.7 Spacers and Shims

5.7.1 Definitions

The spacers and shims are part of the roll set. At each shaft, the total lengths of the rolls, spacers and shims are equal to the roll space.

The difference between a spacer and a shim is related to their length, application, and method of manufacturing.

Spacers are long, usually between 0.125 and 6 in. (4 to 150 mm). The spacers are integral part of the roll forming set.

Shims are short (thin), usually 0.001 to 0.100 in. (0.025 to 2.5 mm). The use of shims should be avoided wherever possible.

5.7.2 Spacers

The total length of the rolls is dictated by good design practice. The difference between the available roll space and the roll length is filled with less expensive spacers (Figure 5.77 and Figure 5.100f).

Figure 5.78 shows a typical spacer used by the industry. Spacers are usually manufactured from seamless carbon steel tubes.

- Typical wall thickness is around .5 in.(12.5 mm). Thinner wall tubes are less expensive but the overtightening of nuts at the end of the shafts and other misuses can "extrude" the spacer into a gap created by too large radius at the roll bore or create other problems (Figure 5.79). Large diameter rolls used to form thick material require spacers with substantially thicker wall.

- The minimum and maximum lengths of spacers are restricted by the manufacturing technology. The maximum length is limited by the key cutting capacity and the safe grinding to length. The spacers are part of the roll set; therefore, their length tolerances and the parallelness of their ends are critical.
- The bore is not important as long as it is reasonably smooth and has a plus tolerance for easy installation. The spacer inside diameter is often 0.005 to 0.020 in. (0.12 to 0.50 mm) larger than the shaft diameter.
- Spacers should have keyways but they can have a larger plus tolerance than roll keyways. Spacers installed without keyways can rotate on the shafts. Rotating spacers can damage the shafts and will reduce not only the length of the spacer but also grind into the hardened rolls. The "grinding" action is accelerated by the presence of abrasive materials such as iron oxide, aluminum oxide, chips, and so on, penetrating in between the spacers and rolls.
- Heat-treatment of spacers is not essential but the spacers should be handled carefully and not be abused.
- Spacers should be clearly marked. (For marking, see Chapter 10, Sections 2.1 and 2.2).

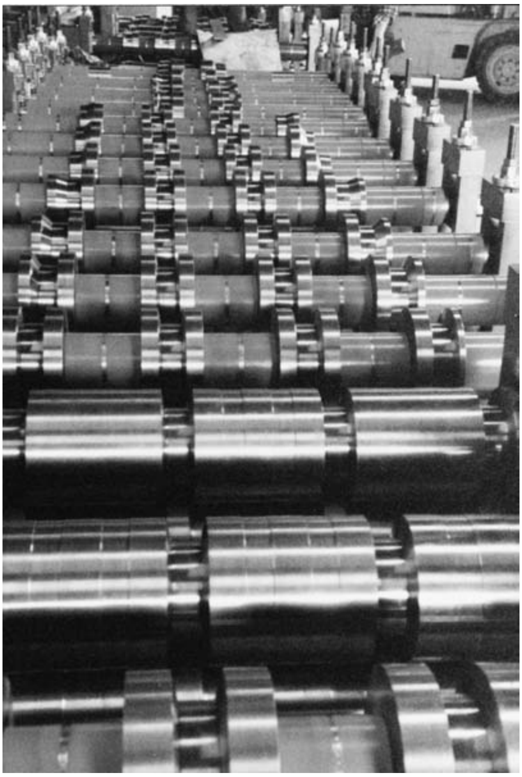


FIGURE 5.77 The difference between the roll space and roll length is filled with less expensive spacers. (Courtesy of Delta Engineering Inc.)

- The marking should be on the outside surface of the spacers in a turned groove. If the spacer is too short to stamp the marking on the outside surface, then it can be stamped on the flat end. In this case, the marking should be made before the final grinding to length operation.

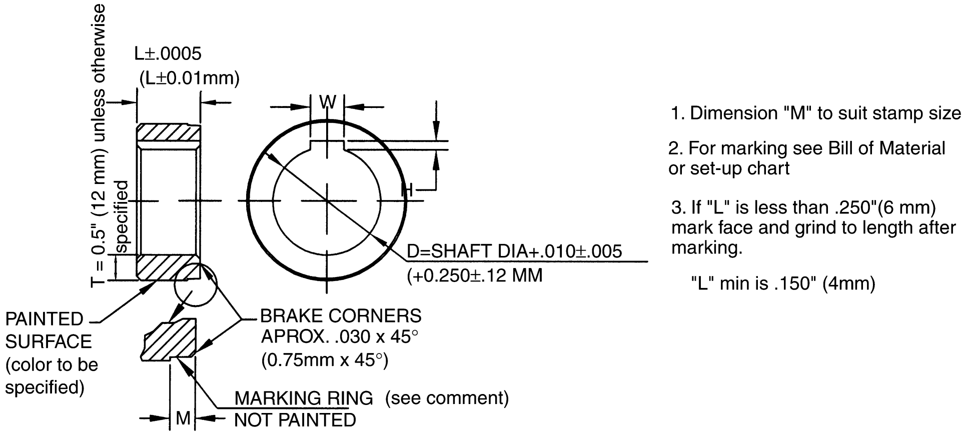

T = 0.5" (12 mm) unless otherwise specified
L±.0005
(L±0.01mm)
W
H
D=SHAFT DIA+.010±.005
(+0.250±.12 MM
1. Dimension "M" to suit stamp size
2. For marking see Bill of Material or set-up chart
3. If "L" is less than .250"(6 mm) mark face and grind to length after marking.
"L" min is .150" (4mm)
PAINTED SURFACE (color to be specified)
BRAKE CORNERS APROX. .030 x 45° (0.75mm x 45°)
MARKING RING (see comment)
NOT PAINTED
M

FIGURE 5.78 Typical spacer (Delta Engineering Standard).

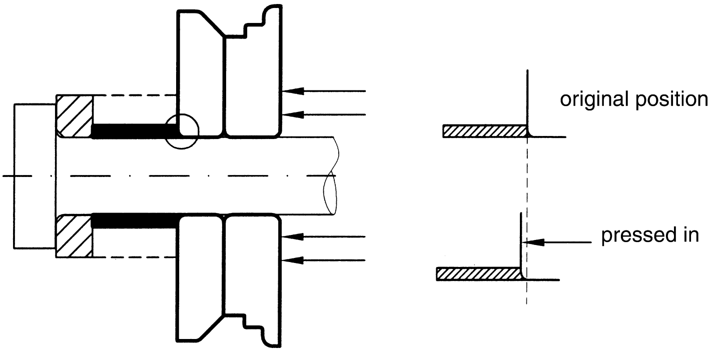


FIGURE 5.79 Thin wall spacers can "extrude" into the large roll radius.

5.7.3 Standard (One-Piece) Spacers

The most frequently used so-called "standard" spacers are made out of one piece as shown in Figure 5.78.

5.7.4 Split Spacers

(a) *Changeover Time.* Split spacers can reduce roll changeover time of multiple width sections. Instead of removing the nuts from the end of the shafts, pulling off the stands, rolls and spacers, it can be sufficient to loosen the nuts and pull the operator-side stand out by approximately 0.25 to 0.75 in. (6 to 20 mm). The gap will allow the removal of the split spacers and the replacement of them into new locations. This method can reduce roll change time by about 70 to 80%. For example, 10 to 24 min per pass changeover using standard spacers can be reduced to 3 to 5 min with nonsplit spacers, depending on the size of the mill, number of rolls, and the experience of the operator.

(b) *Horseshoe Spacers.* Horseshoe spacers were among the first quick removal spacers developed by the industry (Figure 5.80). This type of spacers, as well as the horseshoe shims, create considerable problems. The "open" sections of all horseshoe spacers are in the same direction. In the case of small shaft diameters (1 to 1.5 in. or 25 to 40 mm), the forces applied by overtightening the nuts at the end of the shafts can bend the shafts.

The continuous flexing of the shafts at each revolution can create another problem. The top roll spacers (and the shims) can fall out and damage the next pass rolls. Therefore, manufacturers use spring-loaded ball locators to hold the horseshoe spacers in position. However, it is highly recommended not to use horseshoe spacers at all.

(c) *Bolted and Hinged Split Spacers.* Bolted spacers have been used to avoid accidental falling of spacers from the shafts (Figure 5.81a). These spacers will not fall out but the removal of the screws or other fasteners takes too much time. Hinged spacers (Figure 5.81b) somewhat reduce the time required to remove and install these bolted type spacers.

(d) *Boltless Spacers.* A variety of boltless, quick removal spacers has been developed and successfully used (Figure 5.82a,b).

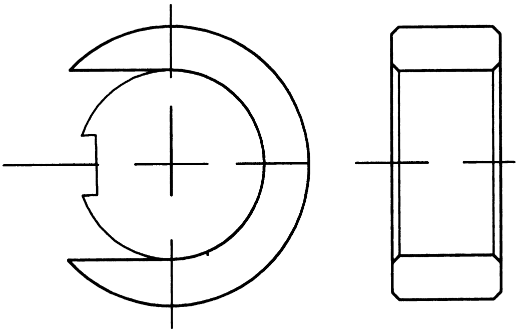


FIGURE 5.80 It is strongly recommended never to use horseshoe spacers.

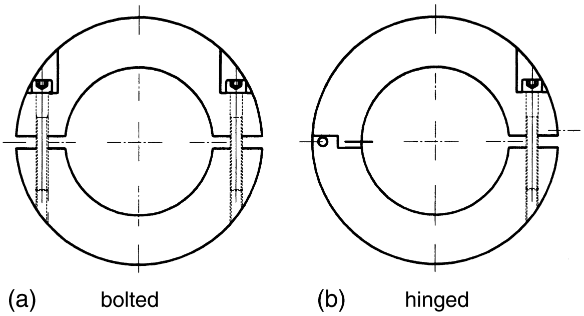
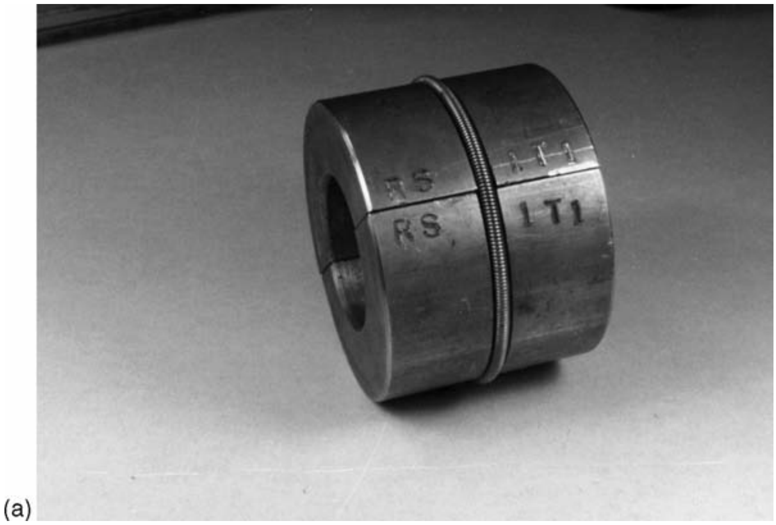


FIGURE 5.81 Bolted (a) and hinged (b) quick removal spacers.



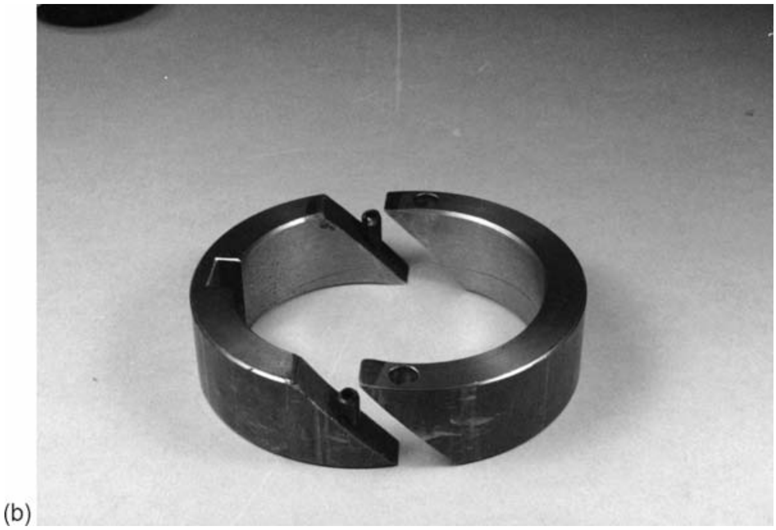


FIGURE 5.82 Quick removal Delta spacers.

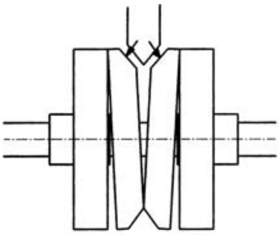
The removal and reinstallation of such a split spacers may take less than 1 min after the operator-side stand is pulled out by a short distance.

Split spacers are more expensive than one-piece spacers, but the extra cost can be quickly recovered by reducing the non-productive time.

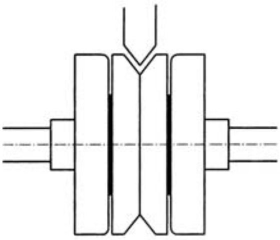
5.7.5 Shims

(a) *One-Piece Shims*. Shims are made out of hard "shim" stock. The bores can be about 0.005 to 0.060 in. (0.13 to 1.5 mm) larger than the shaft diameters. Keyways should be cut into the shims. The outside diameter should be a minimum 1 in. (25 mm) larger than the bore. If the shims or spacers are placed between large diameter rolls (Figure 5.83), then their O.D. should be considerably larger to avoid excessive tilting or bending of the rolls.

Shims should be avoided wherever possible. Shims cannot be properly marked, and they can be easily mixed up and lost. The edges of the thin shims can easily fold over, creating a space of double shim thickness between rolls.



(a) large dia. roll standard shim or spacer



(b) large dia. roll large dia shim or spacer

FIGURE 5.83 Between large diameter rolls, large diameter shims or spacers should be used to avoid tilting of the rolls.

(b) *Split Shims*. Quick-change shims can be easily made by splitting the shims at one side as shown in Figure 5.84a. The use of horseshoe shims (Figure 5.84b) is definitely not recommended for the reasons explained in Section 5.7.4b.

5.8 Calculating Strip Width

5.8.1 Straight and Curved Elements

To calculate the blank size, or in other words, strip or coil width, the final cross-section is divided into straight and curved elements. For blank size calculation purpose, it is assumed that the lengths of the straight elements do not change during roll forming. Calculating the length of a curved element by using the length of its center line (theoretical neutral axis) gives an incorrect, larger starting width than the required width.

For accurate strip width calculation, it is assumed that the theoretical neutral axis of the bent element moves from the half thickness location closer to the inside (Figure 5.85a). The new location of the "relocated" neutral axis is expressed by the bend allowance ("k"). For example, the "k" factor for a low carbon, annealed steel having a bend radius equal to the material thickness ($r:t = 1$) is about 0.33. This means that the new neutral axis, used to calculate the blank size, will be 0.33 times the metal thickness distance from the inside surface of the bent element instead of 0.5 times.

In reality, the material also gets thinner at the corners as shown in Figure 5.85b. The stresses created by the bending are over the yield limit and they cannot change abruptly to zero stress at the end of the curved element. The changeover is gradual, which means a slight thickness change in the straight element too. However, the empirical "k" factor used for the curved element provides an accurate blank size (strip width), with the assumption that the length and the thickness of the straight element are not changing.

The main influencing factors on the empirical "*k*" factor are the inside radius, material thickness, and mechanical properties of the metal.

The larger the *r* : *t* ratio, the closer the "*k*" is to 0.5.

The larger the yield and tensile strength and the lower the elongation, the closer the "*k*" is to 0.5.

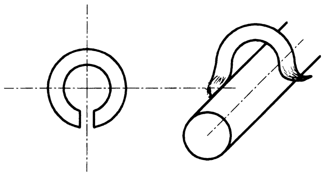
The "*k*" factor has been used to calculate blank size of press brake-formed parts for a long time. Therefore, a large number of equations and tables are available to calculate the length of the bend sections. Almost all tables are different and give slightly different results. Most calculated blank sizes are very close to the actual ones, but the final blank size has to be proven by testing.

An equation to establish the "*k*" factor developed by the author and used in the Roll Former's Guide software is shown in Equation 5.6:

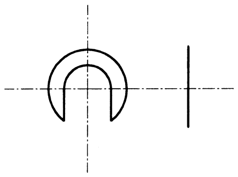
$$k = 0.567\frac{\frac{R_i}{t} + 0.25}{1.2\frac{R_i}{t} + 1} \times \left(1 + \frac{Y^{2.5}}{250U^{1.41}}\right) \qquad \text{(5.6 imperial)}$$

where

R_i = inside bend radius (in.)
t = metal thickness (in.)
Y = yield strength (ksi)
U = tensile strength (ksi)

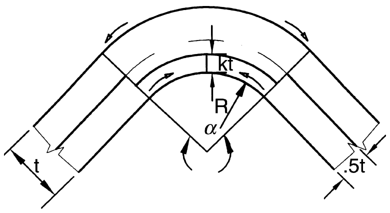

split shim

(a) acceptable

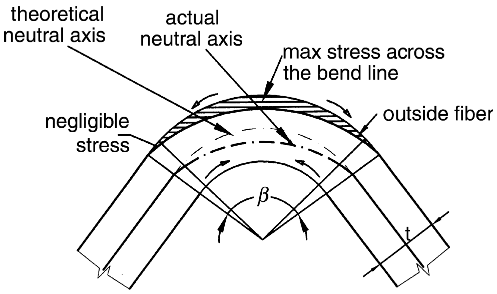

horse shoe shim

(b) not recommended

FIGURE 5.84 Horseshoe shims are not recommended, but split shims can be used.



(a) Theoretical approach



(b) Actual thinning of the bent corner

FIGURE 5.85 The "*k*" factor used in calculations of blank sizes compensate for the actual change of length at the bend lines.

5.8.2 Manual Calculation of Strip Width

Each cross-section consists of straight and curved element. The manual calculation of the strip width required for a curved element is shown below (see Figure 5.86).

t = thickness
k = bend allowance
R_i = inside bend radius
R_n = neutral axis radius
$R_n = R_i + k_t$
L = length of the bent element
α = angle of bending in degrees

$$L = 2R_n\frac{\alpha}{360}\pi$$

$$L = 2(R_i + kt)\frac{\alpha}{360}\pi$$

$$L = \frac{\pi}{180}(R_i + kt)\alpha$$

The equation to calculate the strip width "*L*" required for a bent element is:

$$L = 0.0174533(R_i + kt)\alpha \qquad (5.7)$$

If H and α are given (Figure 5.87a–c)

$$\tan\frac{\alpha}{2} = \frac{a_i}{R_1} = \frac{a_o}{R_1 + t} = \frac{b_o}{R_2 + t}$$

$$a_i = R_1 \tan\frac{\alpha}{2} \quad b_o = (R_2 + t)\tan\frac{\alpha}{2} = a_o$$

$$a_i + b_o = \tan\frac{\alpha}{2}(R_1 + R_2 + t)$$

$$\text{if } R_1 = R_2, \text{ then } a_i + b_o = (2R + t)\tan\frac{\alpha}{2}$$

During strip width calculation, it is assumed that the lengths of the straight elements are not changing during forming. However, if the lengths of the straight elements are not shown on the drawings, they have to be calculated. For the lengthy manual calculations, see a typical cross-section shown in Figure 5.88 and the equations below.

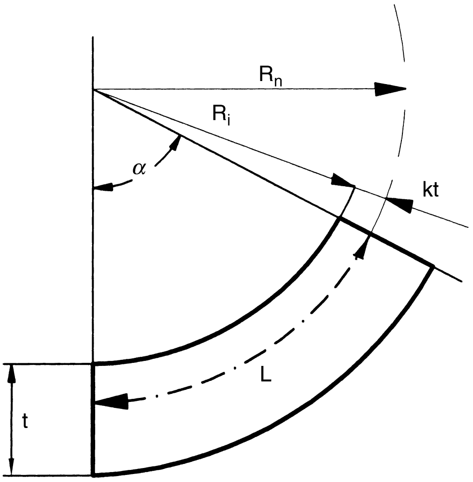


FIGURE 5.86 Calculating the length of curved element ("*L*") for computing strip width.

If $R_1 = R_2 = R$, then $a_i = b_i$ and $a_o = b_o$

$$V = L\cos\alpha + (2R + t)\sin\alpha \qquad (5.8)$$

If $R_1 \neq R_2$

$$L = \frac{H}{\sin\alpha} - R_1\tan\frac{\alpha}{2} - (R_2 + t)\tan\frac{\alpha}{2} \qquad (5.9)$$

If $R_1 = R_2 = R$

$$L = \frac{H}{\sin\alpha} - (2R + t)\tan\frac{\alpha}{2} \qquad (5.10)$$

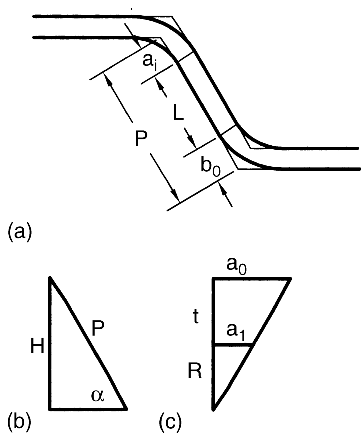


FIGURE 5.87 Calculating blank size.

If H, A_o, and α are given, and $A = A_o - a_o$

$$A = A_o - (R + t)\tan\frac{\alpha}{2} \qquad (5.11)$$

If H, B_o, and α are given

$$B = B_o - (R_2 + t)\tan\frac{\alpha}{2} \qquad (5.12)$$

If H, A_i, and α are given, and $A = A_i - a_I$

$$A = A_i - R_1\tan\frac{\alpha}{2} \qquad (5.13)$$

and

$$B = B_1 - R_2\tan\frac{\alpha}{2} \qquad (5.14)$$

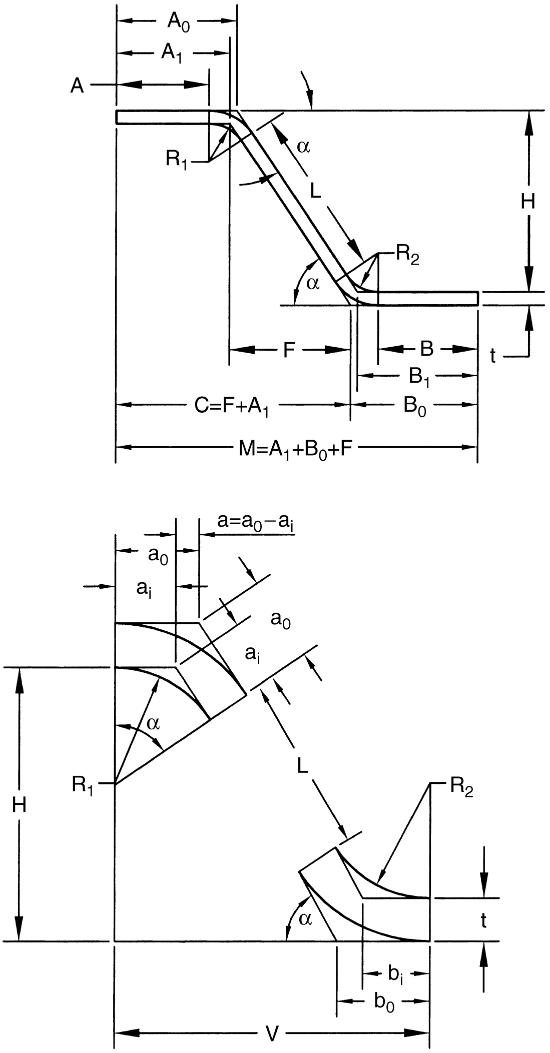


FIGURE 5.88 Schematics illustrating blank size calculations.

5.8.3 Manual Calculation of Blank Size: Example

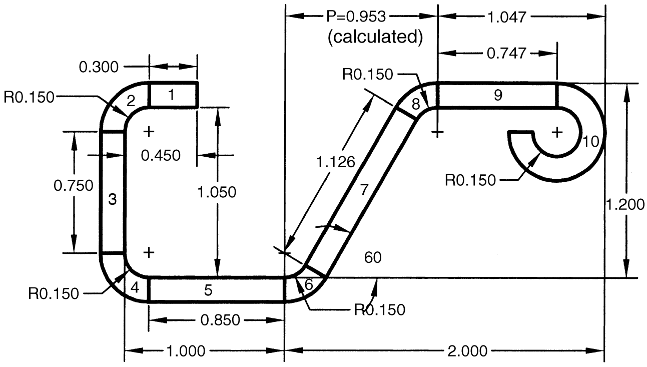
Figure 5.89 shows a typical cross-section prepared for manual blank size calculation. The corresponding calculations are shown in Table 5.4.

With the widespread application of computers and CAD software, these time-consuming manual calculations are less and less frequently required.

5.9 Bend Lines

5.9.1 Bent Elements

The cross-section of roll formed parts can be divided into straight and curved elements (Figure 5.90). The curved elements from the original flat position can be bent in different ways. They can be formed with constant arc length or with constant radius or with a mixture of constant arc length and constant radius.



Material thickness T= 0.150 Bend allowance K = 0.33

$P = L_7 \cos \alpha + (2R + T) \sin \alpha$ $\alpha = 60°$

FIGURE 5.89 Manual blank size calculation of a cross-section.

TABLE 5.4 Manual Blank Size Calculation

#	Calculation	Length
1	0.450-R	0.300
2	0.017453*(R + k*T)*90	0.314 (5.7)
3	1.05-2*R	0.750
4	0.017453*(R + k*T)*90	0.314
5	1-R	0.850
6	0.017453*(R + k*T)*60	0.209
7	1.2/sin60-(2*R + T)/tg30	1.126 (5.10)
8	0.017453*(R + k*T)*60	0.209
9	2-P-R-T (P = 0.953)	0.747 (for "P," see Figure 5.91)
10	0.017453*(R + k*T)*270	0.940
	Total blank (strip) width	5.759

5.9.2 Constant Arc Length Forming

The full length of the bent element (L) designated for the bending is formed at each pass to a progressively smaller and smaller radius (Figure 5.91).

Once the "L" is calculated (Equation 5.7), the inside radius (R_i) at each pass can be calculated from the total angle of the bend (α) at that pass. (For details, see Figure 5.86 where "k" is the bend allowance and "t" is the thickness of the material).

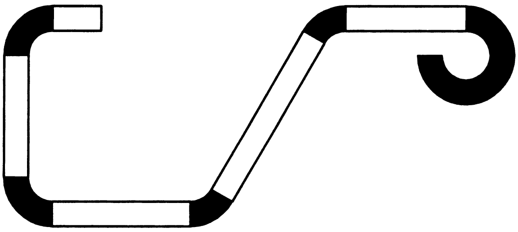


FIGURE 5.90 All cross-sections are divided into straight and curved elements.

$$R_i = 57.2958\frac{L}{\alpha} - kt \tag{5.15}$$

5.9.3 Constant Radius Forming

One or more segments of the element to be bent are formed to the final radius at each pass (Figure 5.92). The roll designer selects the segment of the arc element, which is bent in a specific pass. The segment to be bent can be at one end of the curved element, forming the adjacent straight piece to the finished radius in the next pass and so on (Figure 5.92a). The bending may start at both ends of the element to be bent, then forming the adjacent ones and finally finishing up at the center (Figure 5.92b). Another possibility is to form the center part to the finished radius, then forming the adjacent segments on the next pass and so on until the bending of the element to the specified angle is completed (Figure 5.92c), or the bending sequence of the elements can be mixed (Figure 5.92d).

The length of segment to be formed at each pass can be calculated in the following way.

Total length of the element to be bent can be calculated by using Equation 5.7

$$L = \frac{\pi}{180}(R_i + kt)\alpha$$

if the total angle to the bent is α (Figure 5.93) and the bending angle increment from one pass to the next pass is β, then the segment length (L_1) to be bent to the final R_i is:

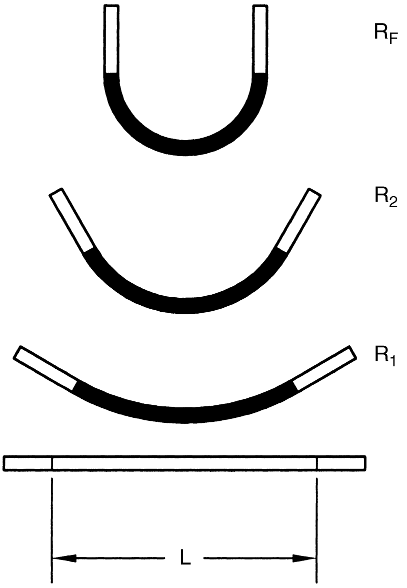
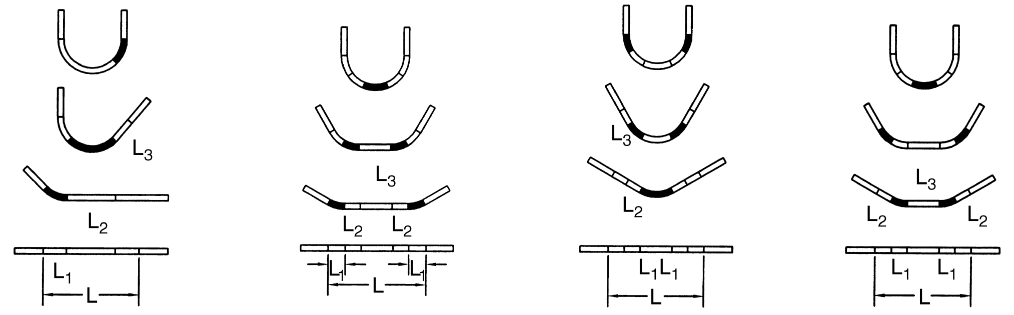


FIGURE 5.91 Constant arc bending in three passes (dark sections are formed).

$$L_1 = \frac{\beta}{\alpha}L \tag{5.16}$$

Example

If the final angle is 90° and the bend angle increase at a given pass is 22.5°, then the length of element to be bent at that pass is $(22.5 \div 90)L$ or 0.25 times the total length of the curved element (Figure 5.93b). If it is decided to bend the element at two places in this pass, then each element will be bent by $22.5 \div 2 = 11.25°$. Therefore, the length of each half element will be $0.125L$ (Figure 5.93c).



(a) Starting one and (material for bends taken from one end)

(b) Starting at both ends (material for bends taken from the center)

(c) Starting at center (material for bends taken from the ends)

(d) Mixed sequences

FIGURE 5.92 Constant radius bending in three passes.

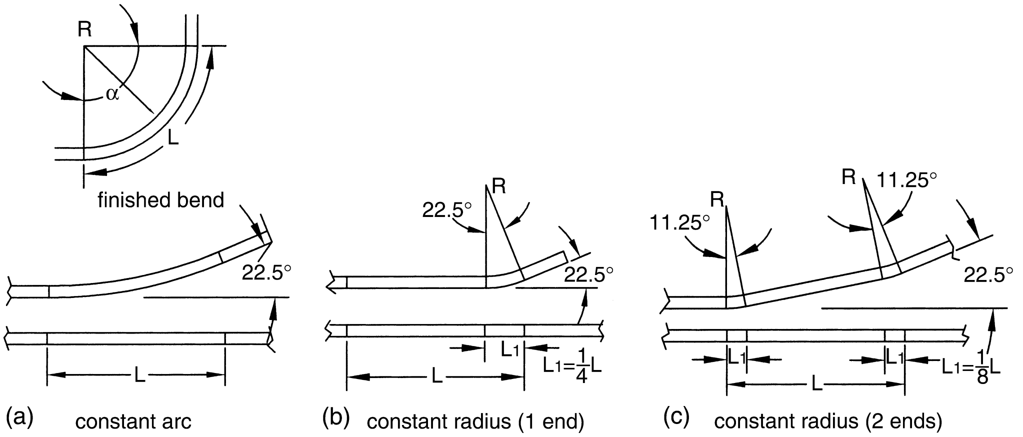


FIGURE 5.93 Calculating the length of bent elements formed with constant arc or constant radius.

5.9.4 Mixture of Constant Arc Length and Constant Radius Forming

Occasionally, although rarely, the designer uses constant arc length up to the point where a roll can fully reach the inside of the bend line, then switches to the constant radius for the next sequence of the bend line (Figure 5.94).

5.9.5 Which Method to Use

No straightforward rule exists to dictate which approach to take except in a few cases. For example, the constant arc method is recommended when blind corners are formed. In a blind corner, the male die cannot reach into the inside of the bend line. Therefore, it is not possible to specify that only one segment of the bend line should be formed to the specified radius.

Constant arc method is also favored when several bend lines are formed at the same time, such as the case with siding, roofing, and many other sections. The larger radii used in the constant arc method allows a "slip in" or "slip-out" of the material in the first few passes of forming, instead of trapping it with the smaller, final radius.

In principle, constant radius bending can be used only when both the male and female rolls are in contact with the bend line. Therefore, constant arc bending is recommended in all "free" bending cases.

The following two examples show two products where forming with constant radius has definite advantages. The first one, Figure 5.95a shows a product with very large radius (large $r:t$). Using constant arc method requires so much overbending at the last pass (Figure 5.95b) that the section would not fit into the mill. Using constant arc, each segment of the arc can be overbent a percentage of the total

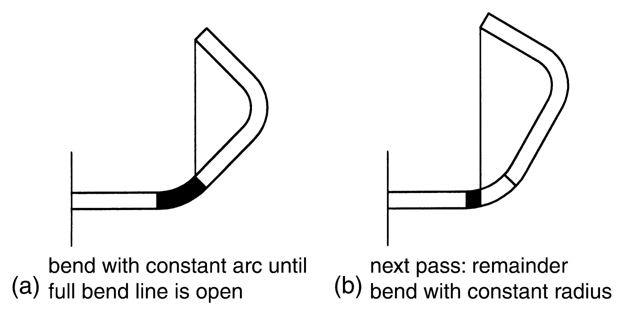

(a) bend with constant arc until full bend line is open
(b) next pass: remainder bend with constant radius

FIGURE 5.94 Forming with combination of constant arc and constant radius.

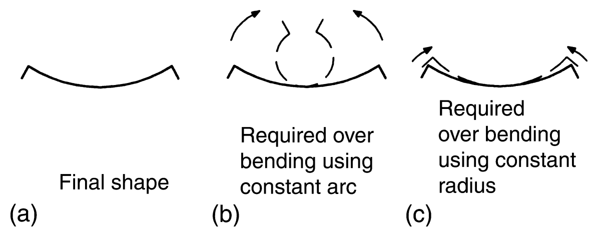

Final shape
Required over bending using constant arc
Required over bending using constant radius
(a)
(b)
(c)

FIGURE 5.95 Forming large radius with constant arc and overbending at each pass require less overbending at the last pass then forming with constant arc.

required overbending. Therefore, the last pass overbend will only be the fraction of the total overbend (Figure 5.95c).

The other example shows a high strength material exhibiting 25° springback formed into a "U" channel. Using constant arc length forming, after reaching the 90°, a 25° overbend would be required. 25° overbend cannot be made in narrow sections because the "legs" will touch each other.

If the forming is made in, say, 10 passes and constant radius forming is used, then each arc segment at each pass should be overbent by 25 ÷ 10 = 2.5°. This means that at the last pass the overbend will need to be only 2.5° and not 25° (Figure 5.96).

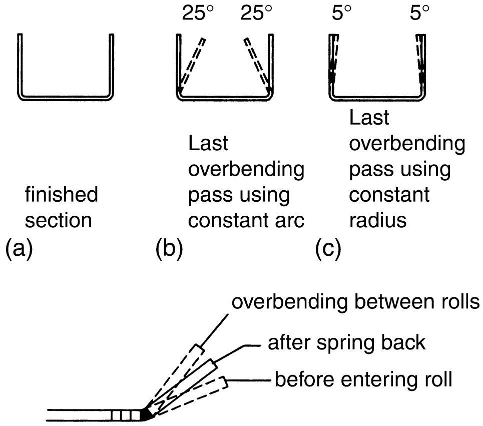

25°
25°
5°
5°
finished section
Last overbending pass using constant arc
Last overbending pass using constant radius
(a)
(b)
(c)
overbending between rolls
after spring back
before entering roll

FIGURE 5.96 Overbending UHSS "U" channel at each pass using constant radius method.

Choosing between constant arc and constant radius, or using a mixture of the two is up to the designer and frequently is dictated by his/her experience. Therefore, recreating roll drawings by measuring the used, worn rolls, and "double guessing" the method used by the designer of the original set of rolls is much more complex, difficult and time consuming than to design a complete set of new rolls.

5.9.6 False Bend

Occasionally, it is necessary to bend and then restraighten elements which will eventually be straight after roll forming are completed. This method is applied during false bending.

- When a radius is "flattened" at a later stage of forming (Figure 5.97a,b)
- To reach otherwise hidden bend lines (as shown in Figure 5.98a)
- When the leg angles are adjusted by this type of bending (Figure 5.98b–d)
- When it is anticipated that the forming of "legs" would also bend the adjacent short straight element especially in the case of thick material (Figure 5.99)

False bends require unusual blank size calculation. During the bend, the material stretches. The increase of the element length can be calculated by using the "*k*" factor. However, when the same element is straightened, it does not "contract." In the opposite, it stretches again. Therefore, a finished width of a straight element containing a false bend made with a sharp radius will be slightly longer than before bending and flattening.

To compensate for this width increase caused by the false bend, a slightly smaller than the normally applied "*k*" factor should be tried for the first test. If the false bend is made with large radius and the "*k*" factor is 0.5 or close to it, adjustment in the blank width calculation is not required. The properly calculated blank for a section with sharp false bend will be slightly less than the same section without false bend.

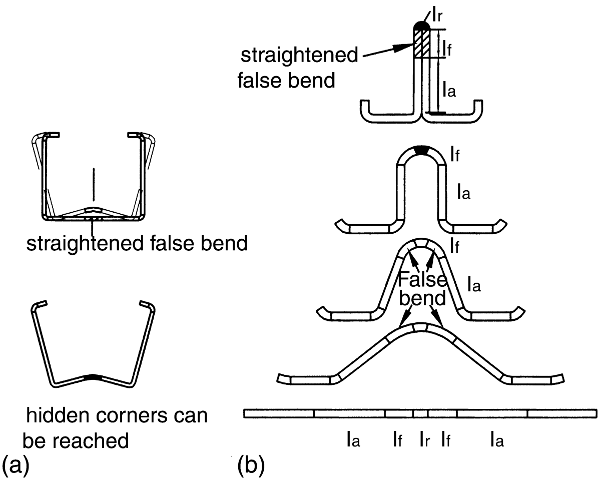


FIGURE 5.97 "False bend" is flattened at a later pass.

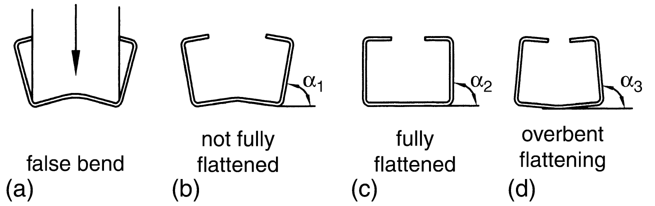


FIGURE 5.98 Angle ∝ can be adjusted by the degree of "flattening."

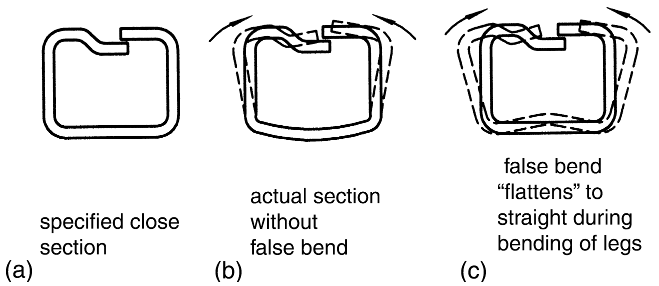

specified close section
actual section without false bend
false bend "flattens" to straight during bending of legs
(a)
(b)
(c)

FIGURE 5.99 Eliminating cross-bow with false bend in narrow, closed sections formed from thick material.

5.9.7 Side-Rolls

In addition to the conventional forming rolls mounted on parallel, horizontal shafts, side-rolls are frequently used for many forming operation. Side-rolls have similar functions as the main rolls and are equally important. Side-rolls have had a bad reputation in the industry for a long time. The reason is that the usually conservative roll designers have aimed to complete the forming with the main rolls. If tool testing revealed that additional forming or guiding was required, then often the setup man tried to cure the problem in the least expensive way. Flimsy side-roll stands with cam followers frequently made the product acceptable. However, it is cumbersome to properly setup and adjust these side-roll stands.

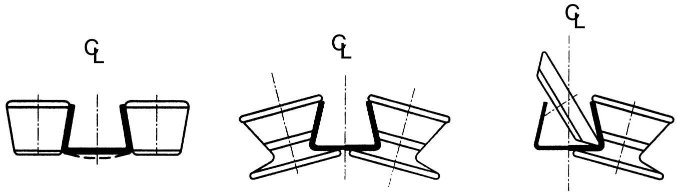
Side-rolls do the same work as the main rolls. Side-rolls are extensively and successfully used in tube forming and should be more widely used in roll forming. Side-rolls should be incorporated in the original roll design. The forming with side or cluster-rolls should be a separate "pass" in the flower diagram.

The side-roll stands should be of good quality, easily, and accurately adjustable. Side-rolls are repeatedly used to control variable springback, and often they are adjusted more frequently then the main rolls.

There is no rule that all shafts must be in horizontal position. Shaft positions should be selected for optimum forming, reaching inside and enveloping the outside of the bends and to minimize speed differential between the rolls and the formed sections. "Free-running" rolls will adopt the speed of the strip, will reduce the friction, and hence will less likely to scratch the surface of the product.

Side-rolls, with a few exceptions, are not driven. Therefore, they must be used in conjunction with driven main rolls. However, if the "free-running" nature represents a restriction, then it is recommended to drive the side-rolls.

Typical side-rolls are shown in Figure 5.100a–f and Figure 5.26. Side-rolls are usually placed between main passes. To be effective and to avoid undue residual stresses, the horizontal distances between the main passes and the side-rolls should be sufficiently long. It is a common mistake to "squeeze" side-rolls between the main passes already having a short horizontal distance (Figure 5.101). This arrangement can increase flare, create waviness, and other problems. Ideally, side-rolls should be positioned at the same horizontal distance as the main stands.



(a) unsupported bottom (b) supported bottom (c) including male roll

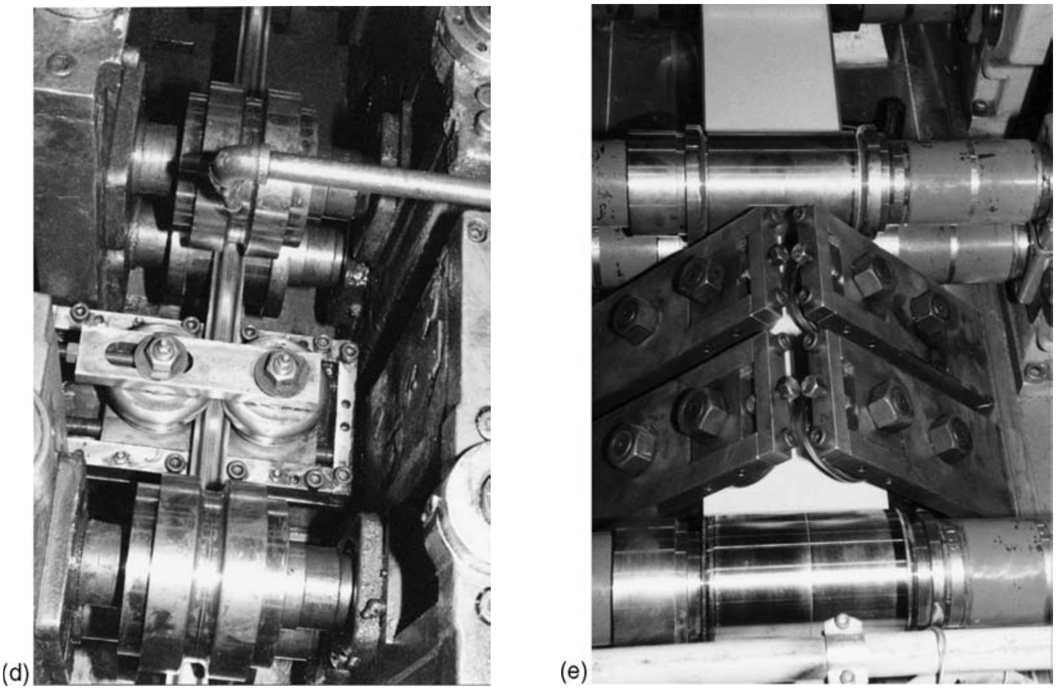


FIGURE 5.100 Typical side-roll stand forming or overbending. (a, b, and c) "U" channels. (d) Hat section. (Courtesy of Delta Engineering Inc.) (e) Lips. (Courtesy of Delta Engineering Inc.) (f) Building panel. (Courtesy of Metform International Ltd.)

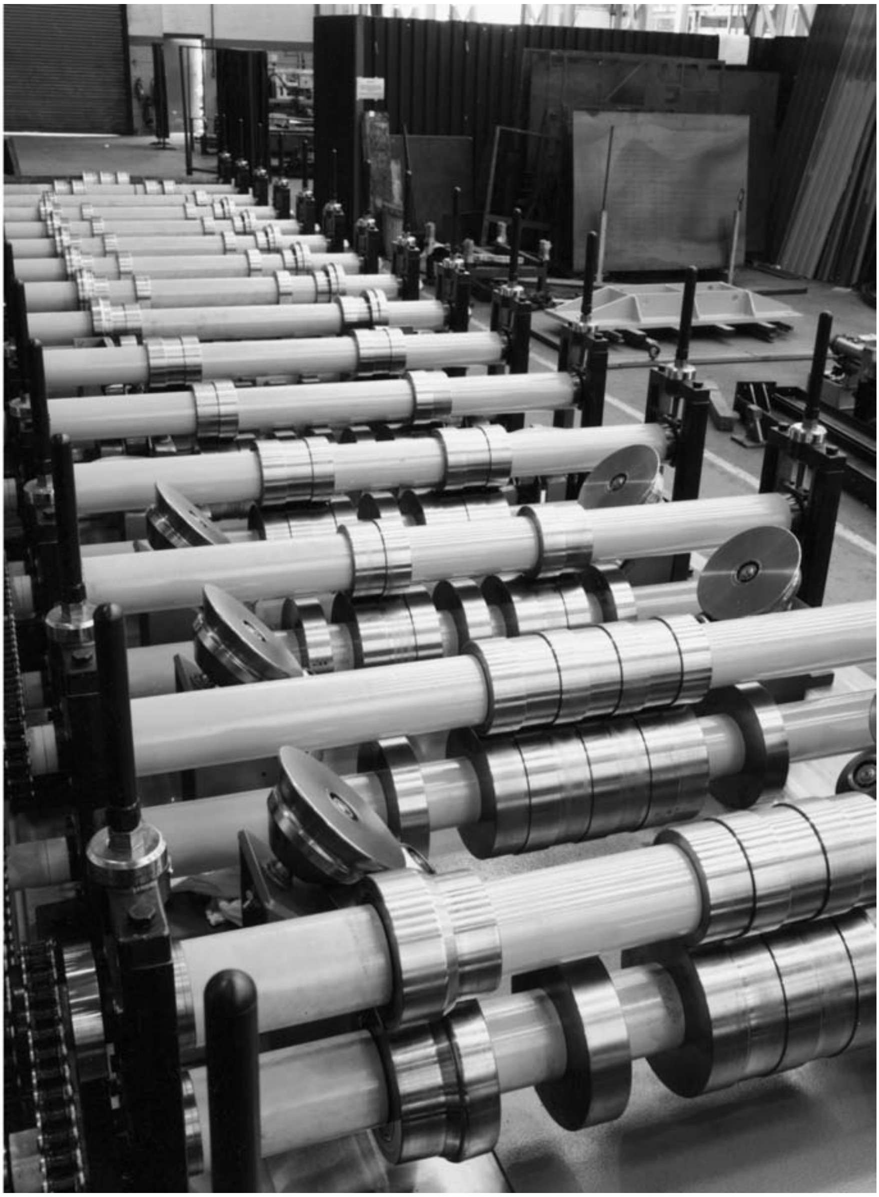


FIGURE 5.100 Continued

The shape of the side-rolls is just as important as the shape of the main rolls. To provide reasonably "smooth" forming, the diameters should also be adequately large. Side-rolls are usually designed the same way as the main rolls. However, some of the side-rolls used for overbending can create a problem when they are only partially engaged. Figure 5.102a shows a typical example where the side-rolls designed for the maximum 10° overbend are set to form only a required 5° overbend. Special Delta overbend rolls have been developed to avoid this problem. The rolls, hinged around the bend line, are "tilted" at the required angle (Figure 5.103).

When a side-roll is applied to one element to the section, the created bending moment may curve the adjacent element too (Figure 5.104a). To avoid this problem, the other elements of the section should also

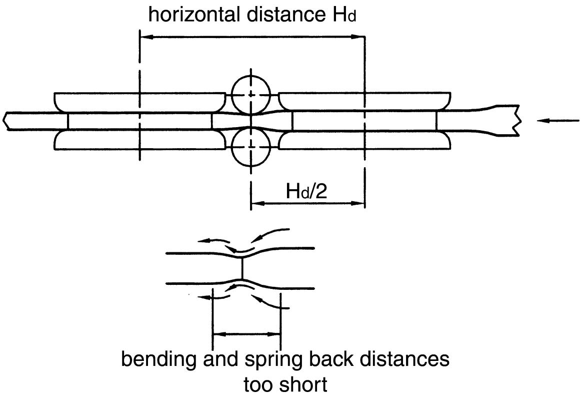


FIGURE 5.101 Side-roll pass squeezed between main rolls may create too high internal stresses.

be supported (Figure 5.104b,c). Special side-roll stands supporting the bottom of the section and rotating in or out will eliminate all these problems.

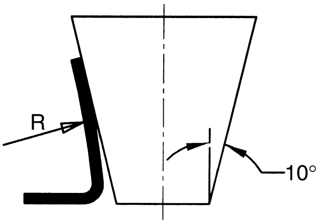


FIGURE 5.102 Conical side-rolls may curve straight legs while bending at the corner.

5.9.8 Cluster-Rolls

To better control the forming process, the side-roll stands can be located at, and working in conjunction with the main rolls. These types of side-rolls are called "cluster" rolls. The cluster-rolls are efficient. They require a special "bridge" stand to support the rolls between the main roll shafts. A typical cluster-roll arrangement is shown in Figure 5.105. Cluster-rolls are also shown in Figure 5.176.

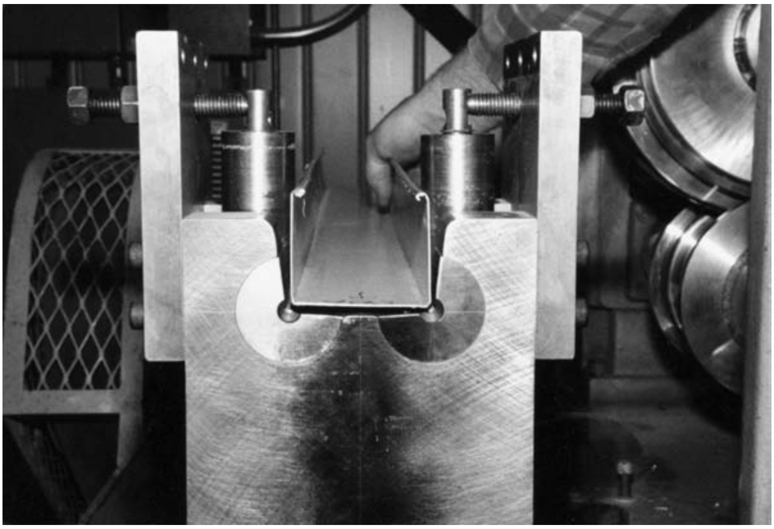


FIGURE 5.103 Side rolls "tilting" around bend lines eliminate edge curving problem shown in Figure 5.102.

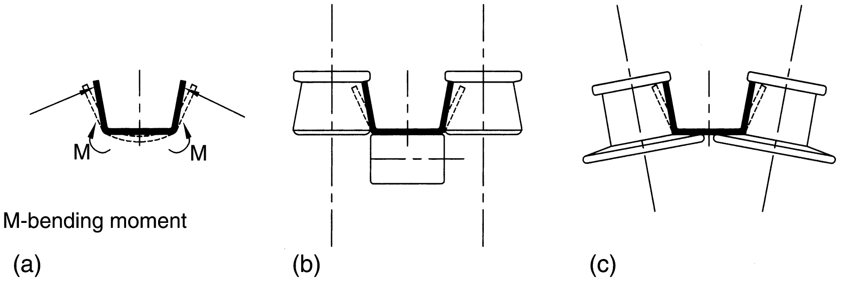


FIGURE 5.104 Supporting the horizontal surface in (b) and (c) eliminates buckling caused by the bending moments (a).

5.9.9 Slides and Other Forming Devices

During the roll setup and testing, the setup person occasionally finds a way to eliminate problems by pushing or squeezing the section with a 2 × 4 piece of wood or by other means. This temporary solution is usually replaced with side-rolls or occasionally with slides made from bronze, plastic or other material. Bronze, hardened steel or other guides are also employed to guide the strip from pass to pass, especially in the case of precut or deeply notched sections. Similar guides may be used to help he strip or section to enter into other tools such as straighteners, cutoff dies.

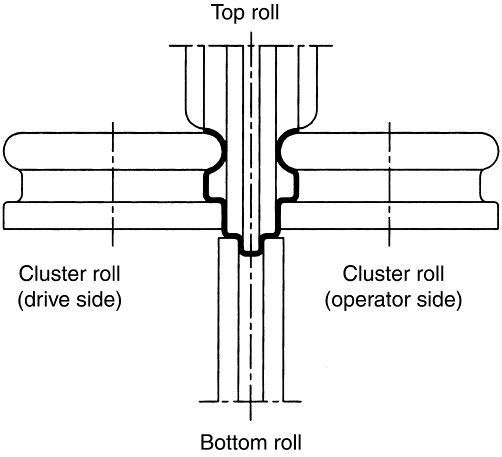


FIGURE 5.105 Cluster-rolls.

These slides (guides) are not considered as forming passes and are not part of the flower diagram.

5.10 Number of Passes

5.10.1 Art or Science

One of the most frequently asked question in the roll forming industry is the number of passes required to form a section. To answer is not easy.

The required number of passes is influenced by many factors including competitive pricing. A standard method of calculating the optimum number of passes required does not exist. Most designers' results are based on experience. The most commonly used process is described by F. Graduous [55]: "The experienced roll designer doodles a bit, gazes at the ceiling and quite positively says: 'I can do it in ten'."

5.10.2 Factors Influencing the Number of Passes

Most of the factors influencing the number of passes have been discussed in Section 5.2 to Section 5.5. Additional factors include the following:

(a) *Material Thickness*. The thickness of the product has an influence, but the effect is controversial. Many designers believe that thicker products require more passes. This is valid only if the mill is

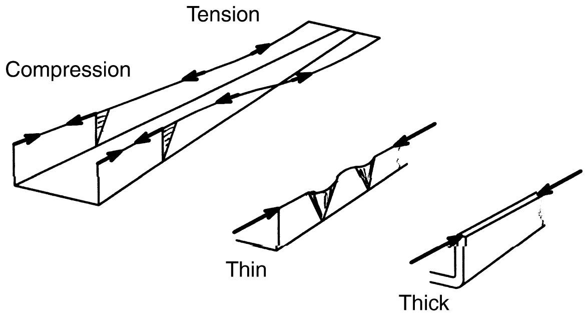


FIGURE 5.106 The buckling strength of thicker and higher strength material is higher; therefore, it is less likely to buckle under compression than the thin or low strength material.

not strong enough to accomplish the required forming at each pass. If the mill is strong enough, which it should be in the majorities of cases, then the thicker the material, the less passes are required. This effect can be explained by the fact that the thickness does not limit elongation (strain), but thicker material will less likely be wavy when compressed in the longitudinal direction (Figure 5.106).

This effect is confirmed by many cases where narrow sections or wide panels can be satisfactorily formed from different thickness of materials down to a limit. Material thinner than this limit requires more passes for good forming, otherwise the product will be wavy or will have other problems.

(b) *Continuity of the Strip.* Continuous forming provides a smoother flow of the material from pass to pass. The flow is different when the part is precut. The leading edge of the strip will slightly spring back after leaving the forming pass, and will travel practically in a straight line until the front end hits the lead-in flange of the next pass of rolls. Abrupt forming therefore takes place on entry to the next pass. The rest of the precut strip is formed as a continuous section, but a similar "jump" happens every time when the front end of the strip contacts the next forming pass. Similarly, there will be difference in the flow when the tail end of the strip exits from the passes.

To minimize abrupt forming, precut strips are usually roll formed with two or three more passes than the same section formed from a continuous strip. The front and tail ends of precut sections frequently have more flare than the same section formed from continuous strip cut to length after forming.

Applying a straightener or curving unit after forming precut strips is either not practical or quite complicated.

(c) *Holes and Notches.* Notches at the edge of the strip have a similar effect on forming as precutting. The deeper the notch, the more similar the effect is to precutting (Figure 5.107 and Table 5.5).

Holes punched in the web have little influence on the number of passes. However, holes punched in the elements which are under tension during forming can greatly influence the required number of passes. In extreme cases, products with large cutouts close to the elements exposed to highest strain require 30, 50, or 80% more passes to be formed than the same section without holes. Insufficient number of passes will distort the shape of the holes.

Very large cutouts, like complex miter prenotches will make roll design more difficult. At the point of a large cutout, the remaining strip is very weak, but it should neither be permanently stretched nor compressed during forming. This cross-sectional weakness will also create problems when the strip passes through a loop after punching, when the material is forced through the straightener, and when the finished product is handled after forming.

The number of passes is established to keep the stresses at the edges of the strip at around or just above the yield point. When wire webs or sections slit to the edges (Figure 5.108) are roll formed,

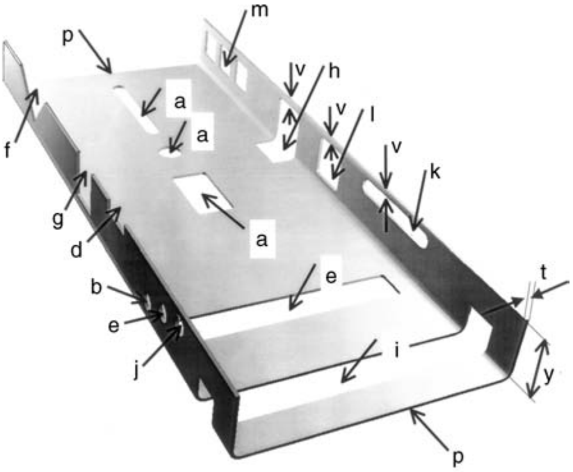


FIGURE 5.107 Influence of holes and notches on the number of roll forming passes.

the edges are not constrained and high stresses are not developed. Therefore, roll forming these types of starting materials require less passes than the same section made from solid, continuous strip. The lead-in flanges of the rolls should be sufficiently large to ensure a smooth entry of the edges into the roll gap. However, the variation in the circumferential speed can change, say, a 90° angle of the "fingers" by 3 to 6°. Care should be taken to avoid or minimize this problem.

(d) *Straight or "Free-Flow" Pass Line*. Almost all roll designers' experience, as well as roll design software, are based on forming sections in a roll forming mill which has all the bottom shafts in a straight (usually horizontal) line. A straight pass line is not necessary ideal for roll forming, as explained in Chapter 15. If rolls are designed to suit the optimum material flow ("free-flow" or "down-hill forming"), where the pass line is not a straight line, then the number of passes can be reduced compared with the passes used with the present methods (Chapter 15).

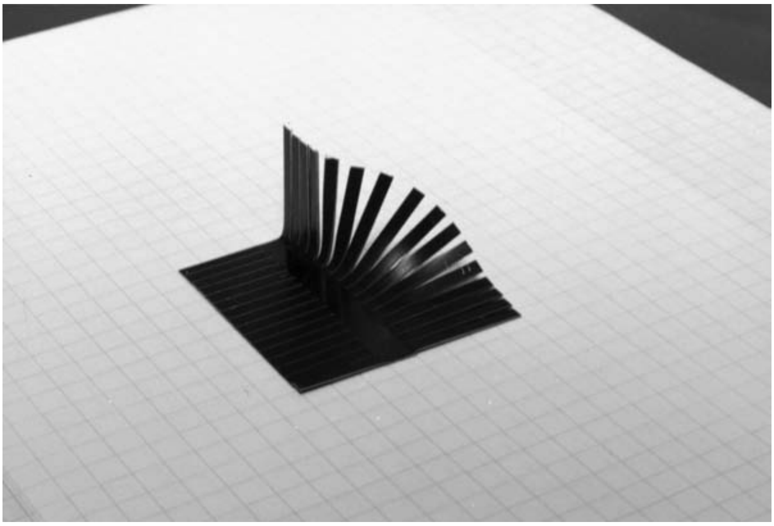


FIGURE 5.108 Noncontinuous edge will "open up" instead of "stretching," thus often requires less passes to form it.

TABLE 5.5 Factors Influencing the Number of Passes

Factors		**Number of Pass Requirement**	
		Decrease	**Increase**
	Depth of the section	Shallow	Deep
	Bend lines	Open	Hidden
	Section tolerance	Loose	Tight
Material	Thickness		
	If mill is strong enough	Thicker	Thinner
	If mill is not strong		Thinner and thicker
	Mechanical properties	Low yield strength	High yield strength
		High elongation	Low elongation
	Surface	Hot rolled steel	Prepainted or luster surface
	Uniformity (twist, waviness, camber, etc.)	Tight tolerance material	Loose tolerance material
	Continuity	Continuous strip	Precut
Other operations in the line	Holes at the center	No influence	
	Holes close to edges		More passes
	Notches		Shallow (1 to 2 extra)
			Deeper (more passes)
	Welding	—	2 to 4 or more
	Curving	Same or less	—
Mill characteristics	Larger shaft diameter	May be less passes	—
	For deep sections and panels		
	Horizontal distance	Less passes	—
	Large	—	—
	Small		More passes

(e) *Tabulated Form of Influencing Factors*. The number of passes required to form a product within the specified tolerances are influenced by numerous factors as described in the previous sections. Table 5.5 summarizes the overall effects of these factors and Table 5.6 to Table 5.8 provide the numerical values for Equations 5.19.

5.10.3 Calculating the Number of Passes

Numerous attempts have been made for a long time to bring "science" into roll forming or at least to provide some numerical guidelines to calculate the number of passes. One of the earliest approaches was to calculate the distance from the edge of the strip to the edge of the finished product in a simple, straight layout (Figure 5.109). Dividing this distance with tangent 1 − tangent 1.5 in. (0.0175 − 0.0262) gives a guideline for the total mill length required for forming. Dividing the total lengths with the horizontal spacing between passes will give the required number of forming stations (see equation below).

Example

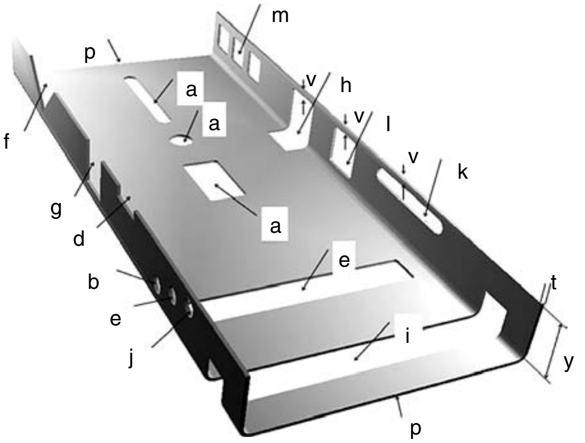
$$p = \sqrt{2a^2} = a\sqrt{2} = 1.414a \tag{5.17}$$

if $a = 1.5$, then $p = 1.414 \times 1.5 = 2.12$

$$\tan\alpha = \frac{p}{c} \qquad c = \frac{p}{\tan\alpha} \tag{5.18}$$

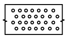
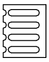
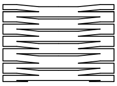
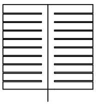
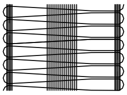
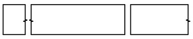
assuming $\alpha = 1.5°$, $\tan\alpha = 0.0262$, then $c = 2.12 \div 0.0262 = 80.96$ = distance from the first pass to the last pass.

TABLE 5.6 Effect of Holes and Notches (*Z*) on Number of Passes (Equation 5.19)



∅ For letter "Z" in the equation pick one number only, the highest value of all applicable conditions

y = height
t = thickness
v = distance from edge

• Small perforation			n_1
			
	edge continuous		n_2
• Slotted	limited edge continuity		n_3
	edge not continuous		n_4
• Wire			n_5
• Pre-cut			p

Z

	$\frac{y}{t}<20$	$\frac{y}{t}>40$
no hole	0	0
a	0	0
b	0	0
c	0	0.07
d	0.03	0.05
e	0.05	0.05
f	0.07	0.12
g	0.07	0.12
h	0.1	0.1
i	0.12	0.15
j	0.12	0.15 (if $s \geq 5t$)
k	0.15	0.2 – 0.4 (*)
l	0.25	0.3 – 0.5 (*)
m	0.5	0.6 – 0.7
n_1	0	
n_2	0.05	
n_3	0.05	
n_4	0.30	
n_5	0.25	
p	0.18	0.18 (pre-cut)

(*) The longer the slot and the smaller the dimension "v", the larger the "Z" factor is.

TABLE 5.7 Effect of Shape (*S*) on Number of Passes (Equation 5.19)

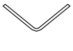
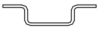
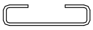
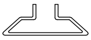
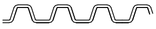
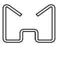
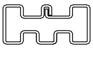
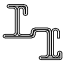
	1	**1**	**1.05**	**1.05**	**1–1.05**	**1.1 – 1.2**	**1.4**	**1.5**
S **Shape Factor**								

TABLE 5.8 Effect of Tolerance Factor (F) on Number of Passes (Equation 5.19)

$\boxed{f}$ **Tolerance Factor**	
Loose (construction)	0
Medium	0.5–1.0
Tight (automotive)	1.1–1.7
Extremely tight	1.9–(2)

If the horizontal distance between passes is HD = 10 in., then according to this equation, (80 ÷ 10) + 1 = 11 passes will be required to form the 1.5-in. deep "U" channel.

The calculation based on Equation 5.18 gives some guidance to "beginner" designers for simple sections but it is "crude," unreliable approach, which does not take other important factors into consideration.

Other author [38] recommends to calculate the number of passes by limiting the "resulting edge tension" as shown in Figure 5.110.

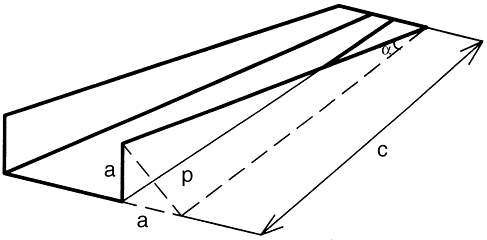


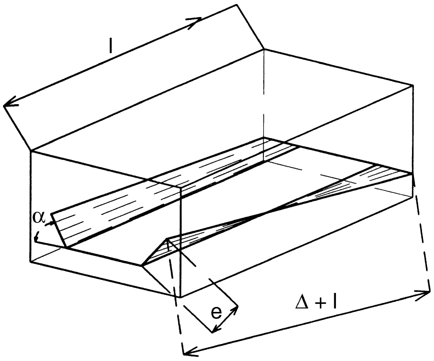
FIGURE 5.109 An early rough "straight line" approach to calculate the number of passes.

With the advance of computer-aided roll design, additional approaches have been tried (see Section 5.14). One method has been based on calculating the stresses in the formed section to arrive at the number of passes required. Another method is to establish the number of passes and prepare a flower diagram first, and then to calculate the developed stresses. If the stress between passes is above the permitted level, then the forming can be modified. Another method of calculating the number of passes with computer-aided roll design is based on empirical equations.

An empirical equation prepared by the author, which provides guideline for the number of passes, is incorporated in the Roll Former's Guide® software. This, so far not fully tested equation is shown below:

$$n = \left[3.16h^{0.8} + \frac{0.05}{t^{0.87}} + \frac{\alpha}{90}\right]\left[\frac{Y^{2.1}}{40U}\right]^{0.15} s(1 + 0.5z) + e + f + 5zs \qquad \text{(5.19 imperial)}$$

$$n = \left[0.237h^{0.8} + \frac{0.834}{t^{0.87}} + \frac{\alpha}{90}\right]\left[\frac{Y^{2.1}}{0.003U}\right]^{0.15} s(1 + 0.5z) + e + f + 5zs \qquad \text{(5.19 metric)}$$

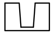
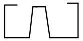
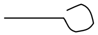
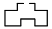
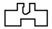
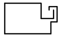
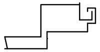
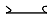
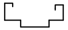
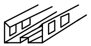
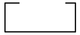
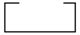


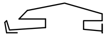
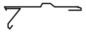
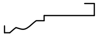
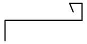
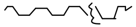
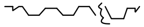
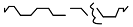
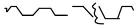
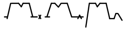
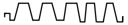
$$\sigma = \frac{e^2 \times E \times (1 - \cos(\alpha))}{l^2}$$

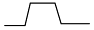
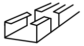
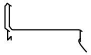
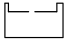
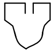
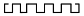
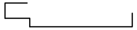
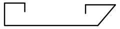
σ = stress
e = leg height
E = modules of Elasticity
l = bending length
α = bending angle

FIGURE 5.110 Calculating the number of passes from limiting edge stress.

TABLE 5.9 Number of Passes Calculated with Equation 5.19

	 Bumper	 W Bumper		 Window spc	 Window spc	 Screen Door	 Screen Door	 Drawer sld	 Door Frame	 Furniture	 Stud	 Auto	 T-hanger
Height	3	2.35	0.375	0.312	0.35	0.75	1	0.5	2.25	0.7	2.5	2.36	1.6
Thickness	0.075	0.06	0.047	0.017	0.017	0.024	0.024	0.096	0.048	0.074	0.036	0.146	0.011
Y	195	160	45	14	14	18	18	45	40	45	65	55	40
UTS	205	180	55	16	16	20	20	55	55	55	80	65	50
Total angle	360	360	195	535	436	450	630	250	360	405	180	184	720
Shape 1–1.6	1.25	1.08	1.2	1.3	1.3	1.35	1.35	1.3	1.05	1.15	1.05	1.05	1.3
Extra pass	0	0	0	1	1	1	1	1	0	1	0	1	3
Tol. 0–2	1.8	1.8	0	1.65	1.65	1.65	1.65	1.6	1	1.2	0	1.9	2
Hole fact 0–1	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.18	1.18	0
No passes	**22.4**	**17.1**	**5.4**	**12.8**	**11.6**	**13.5**	**16.7**	**9.4**	**17.8**	**16.1**	**13.0**	**14.5**	**25.1**
Actual									17	18	14.0	16	26

	 Barn Vent	 Drip Starter	 Canopy			 Guide	 Fan	 1.5 × 8 45°	 1.5 × 8 36°	 1.5 × 5 54°	 2″ × 5 54°	 3″ × 3 ribs 62°	 1.5 × 4 80°
Height	6	1.05	5.4	0.4	1.3	1.6	3.25	1.5	1.5	1.26	2	3	1.5
Thickness	0.015	0.018	0.03	0.006	0.015	0.071	0.048	0.013	0.031	0.013	0.013	0.035	0.036
Y	45	45	45	30	16	50	50	36	25	90	90	90	45
UTS	55	55	55	40	18	60	60	38	28	110	110	110	55
Total angle	640	480	250	240	270	510	280	750	918	490	490	372	640
Shape 1–1.6	1.3	1.3	1.1	1.07	1.05	1.25	1	1.05	1.05	1.05	1.05	1	1.05
Extra pass	0	1	0	0	0	1	0	0	0	5	5	7	3
Tol. 0–2	0.3	0.4	0	1.5	0.5	1.15	0.75	0	0.2	0.2	0.2	0.2	0.2
Hole fact 0–1	0.07	0	0.18	0.18	0.18	0.1	0.18	0	0	0	0	0	0
No passes	**32.1**	**15.4**	**21.1**	**12.0**	**10.5**	**17.9**	**15.5**	**16.1**	**16.0**	**19.3**	**21.4**	**22.1**	**16.8**
Actual		14 passes did not work	?										18

	 Hat	 Step Beam	 Auto					 Auto	 U Bookshelf	 Tubulrar auto	 SS “U” chnl	 Furniture Side	 Furniture Door
Height	0.456	6	0.93	1.1	1.5	0.85	1.2	0.78	0.625	6	2.36	1.44	0.94
Thickness	0.093	0.068	0.093	0.024	0.06	0.024	0.024	0.082	0.06	0.04	0.12	0.026	0.026
Y	50	55	50	40	40	40	40	60	45	45	70	45	45
UTS	60	65	60	50	50	50	50	50	55	55	85	55	55
Total angel	180	270	180	270	270	360	450	880	90	300	90	360	270
Shape 1–1.6	1	1.25	1.05	1.2	1.15	1.2	1.3	1.06	1	1.2	1	1.07	1.07
Extra pass	1	0	1	1	1	0	1	1	0	0	0	0	0
Tol. 0–2	1.7	0.6	1.7	1.2	1.2	1.2	1.2	1.6	1.2	1.7	1	0.5	0.5
Hole fact 0–1	0.4	0	0.5	0	0	0	0	0	0	0.15	0	0.18	0.18
No passes	**9.9**	**23.4**	**12.9**	**#REF!**	**11.5**	**11.1**	**15.4**	**18.4**	**5.1**	**26.1**	**9.6**	**13.0**	**10.3**
Actual				20	Recommended	10	14	20					

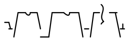
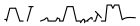
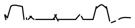
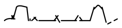
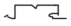
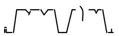
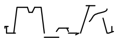
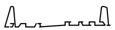
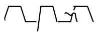
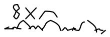
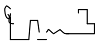
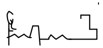
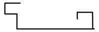
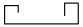
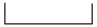
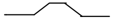
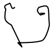
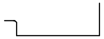
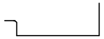
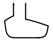
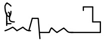
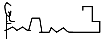
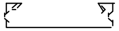
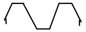
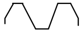
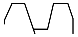
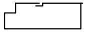
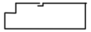
	 1.68 × 476°	1.5 × 5 deck	 0.75 × 5 75°	 Farm Roof	 Farm Roof	 Hidden Fasten	 4 × 3 85°	 2 × 385°	 Farm Roof			 Garage Door	 Garage Door
Height	1.68	1.5	0.75	0.354	0.5	1.5	3	3	1.44	0.8	0.6	0.71	1.71
Thickness	0.024	0.026	0.015	0.032	0.015	0.03	0.026	0.026	0.018	0.032	0.02	0.018	0.018
Y	45	40	45	45	45	45	45	45	48	45	50	50	50
UTS	55	52	55	55	55	55	55	55	60	55	60	60	60
Total angel	608	960	900	594	850	360	680	340	500	562	1200	1570	1570
Shape 1–1.6	1.05	1.05	1.05	1	1	1.25	1	1	1.2	1	1	1.22	1.22
Extra pass	3	0	0	0	1	2	4	8	6	0	12	1	1
Tol. 0–2	0.2	0.2	0.2	0.7	0.2	0.2	0.2	0.2	0.75	0.7	1	1	1
Hole fact 0–1	0	0	0	0.0	0	0	0	0	0	0.00	0	0	0
No passes	**17.3**	**17.5**	**16.1**	**10.1**	**15.0**	**14.5**	**21.3**	**21.4**	**21.2**	**11.0**	**31.1**	**30.0**	**33.2**
Actual	18	18	16		14	14	22	22	20 + 5SR bit wavy				

TABLE 5.9 Continued

											
	FurnitrTop	FurnitrBack	FurnitrStiffnr				Sill	Sill right side			
Height	1.44	1	0.5	0.45	4.6	13.1	4.6	8.5	2.5	0.5	2.25
Thickness	0.026	0.026	0.026	0.026	0.018	0.375	0.35	0.35	0.24	0.24	0.06
Y	45	45	45	45	45	45	60	60	45	45	60
UTS	55	55	55	55	55	55	70	70	55	55	85
Total angle	360	270	90	140	540	60	180	90	90	270	450
Shape 1–1.7	1.07	1.05	1	1	1.05	1	1	1	1	1	1.45
Extra pass	0	0	0	0	0	0	0	0	0	0	1
Tol. 0–3	0.5	0.5	0.5	0.5	0	0.5	0.75	0.75	1.7	1.7	1.6
Hole fact 0–2	0.18	0.18	0.18	0.18	0	0.18	0	0	0	0	0
No passes	**13.0**	**10.3**	**6.0**	**6.4**	**20.2**	**30.5**	**14.9**	**21.3**	**9.8**	**6.9**	**20.7**
Actual									Swept 14	Swept 14	

												
	Garage Door	Garage Door	Garage Door	Guard Rail	Guard Rail	Guard Rail	Rack Beam	Rack Beam	Rack Beam	Rack Beam	Rack Leg	Auto
Height	1.2	1.71	1.82	3.187	3.187	3.187	7	5.5	7	5.5	3	0.8
Thickness	0.018	0.018	0.018	0.1	0.064	0.064	0.078	0.078	0.078	0.078	0.074	0.018
Y	50	50	35	60	60	60	50	50	50	50	60	65
UTS	60	60	45	70	70	70	65	65	65	65	75	80
Total angle	750	450	730	190	190	190	360	360	360	360	180	450
Shape 1–1.7	1.22	1.2	1.1	1	1	1	1.1	1.1	1.1	1.1	1.05	1.2
Extra pass	6	0	0	0	0	0	1	1	1	1	2	1
Tol. 0–3	1	1	1	0.5	0.5	0.25	0.3	0.3	0.3	0.3	0.8	1.6
Hole fact 0–2	0	0	0	0	0	0	0	0	0.18	0.18	0.12	0.18
No passes	**24.8**	**15.7**	**17.3**	**12.1**	**12.3**	**12.0**	**23.9**	**20.8**	**26.9**	**23.6**	**15.7**	**17.2**
Actual							18				16	
		Edges only					18 insufficient big flare					

where

n = number of passes (guideline only)
h = maximum height of the section
t = material thickness
α = total degree of formed angles at one side of the guide plane (whichever side is larger)
Y = yield strength in ksi (MPa)
U = ultimate tensile strength in ksi (MPa)
z = prepunched hole/notch and strip continuity factor (0 to 2; see Table 5.6)
s = shape factor (1–1.6) — (see Table 5.7)
e = number of extra passes (0, 1, 2, etc.). For example, for scoring, grooving, duplicate "last pass," and so on
f = tolerance factor (0 to 2; see Table 5.8)

The accuracy of the guide number for passes depends on the correct input of numbers. Selecting the correct input number requires some experience.

Table 5.9 provides several examples of the application on this empirical equation.

5.11 Flower Diagram

5.11.1 Cross-Section at Each Pass

After the section orientation has been selected and the number of passes established, the first step is to locate a vertical guide plane (often called guideline). A selected element of the cross-section will travel through the roll forming mill in that vertical plane. Typical examples of the effect of the location of the vertical guide plane on a flower diagram and the stresses developed in the section are shown in Figure 5.111. For many sections, the selected element will travel in a straight horizontal line in that plane, while others with a slight increase in the pass line height if the roll diameters are increased from pass to pass (Figure 5.112a). In other sections, the element traveling in the vertical plane may move significantly in the vertical direction if it is required for optimum roll design (Figure 5.112b).

In a few, exceptional occasions, it is advisable to have more than one guide plane. The first guide plane is used up to a given pass and, from the next pass onwards a different guide plane is used. Examples for this unusual technique are shown in Figure 5.113.

After the guide plane is located, the next step is to decide on the sequence and magnitude of bending of each curved element at each pass.

Bending may start at the edges (as shown in Figure 5.3b), or at the center (Figure 5.3a and Figure 5.5), or all bends can be formed at the same time (Figure 5.114 and Figure 5.120a). After the bending angles have been established

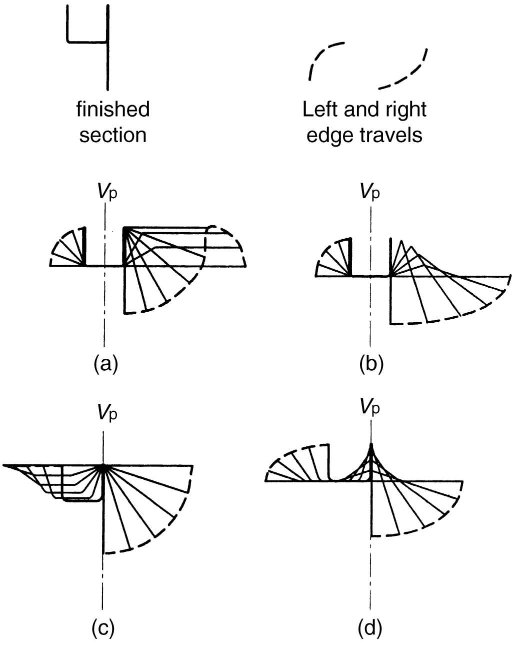


FIGURE 5.111 The edge stress is related to the edge travel shown in the flower diagram. The position of the vertical plane (V_p) influences the edge movement ("a" worse, "d" best).

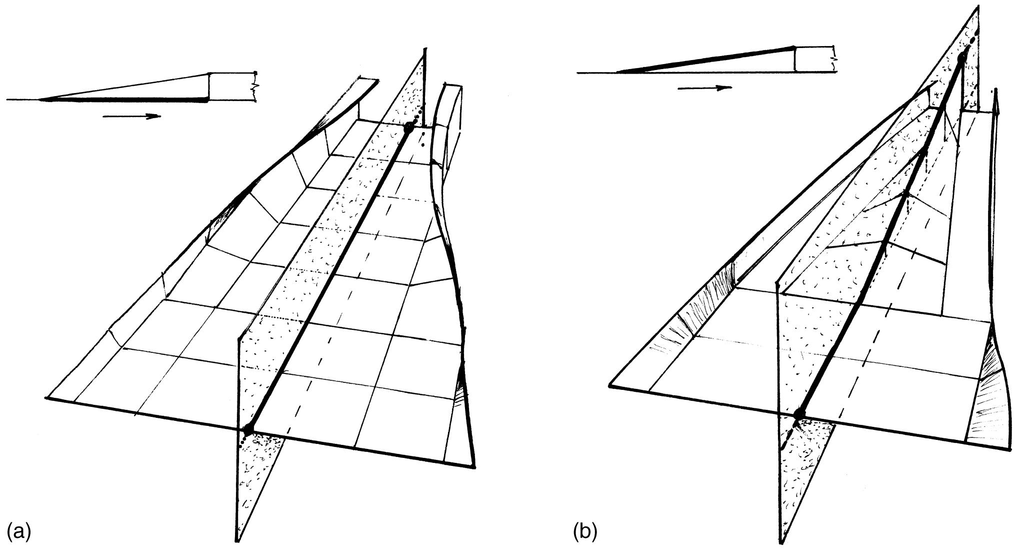


FIGURE 5.112 One point of the cross-section travels within a straight vertical guide plane almost horizontally (a) or may travel up (b) or down.

and the cross-section at each pass is drawn, the designer reviews the access to the bend lines (open or hidden), the overbend requirements to counteract springback and how the forming angles will be adjusted by the operators by moving the top rolls down or up.

The cross-sections at each pass (Figure 5.1), superimposed from the flat strip to the finished shape, is called the standard "flower diagram." Typical flower diagrams are shown on (Figure 5.5, Figure 5.44, Figure 5.111, Figure 5.162, Figure 5.173, Figure 5.174 and Figure 5.178). Occasionally, the large number of cross-sectional lines obscures the sequence of forming. In this case, the "split flower diagram" can be helpful (Figure 5.4, Figure 5.44, Figure 5.113, Figure 5.175, and Figure 5.177).

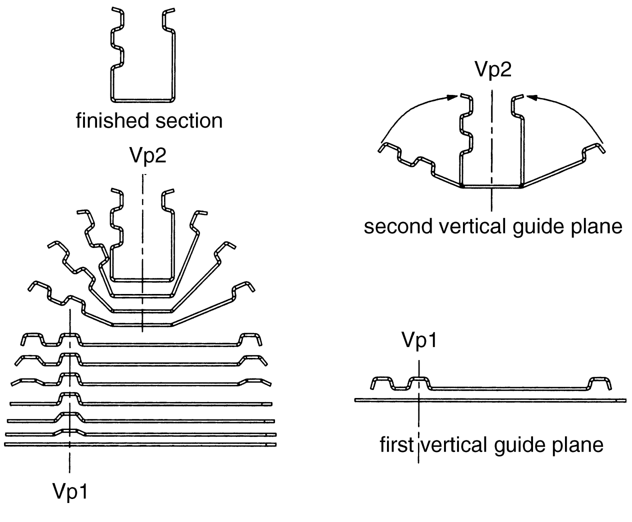


FIGURE 5.113 In very special cases, one vertical guide plane is used for the first part of the passes and another one for the rest of the forming.

With the advancement of computers, it becomes easier to generate top view, side view, or three-dimensional view of the flower (Figure 5.115). For an experienced roll designer, the standard and occasionally the split flower diagrams are sufficient.

The flower diagram is one of the most important aspects of roll design. It reveals the anticipated flow of the material and the magnitude of the stresses generated by the forming process. The designer tries to avoid large “jumps” (marked as “b” in Figure 5.116a,b), resulting in higher stresses at the edges or bend lines. The more even the increments, the less chance there is to run into problems. If necessary, additional pass(es) can be added or some passes can be eliminated. Shorter edge and bend line travel distance will generate less stress. The original flower diagram (Figure 5.117a) may be modified to reach into the corners wherever possible (Figure 5.117b).

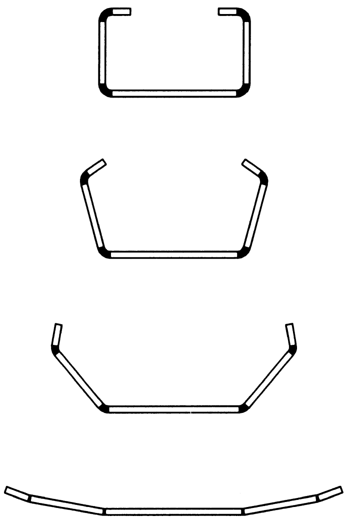


FIGURE 5.114 All bends formed at each pass (only 4 of the actual 12 passes are shown).

To find the best, smooth, uniform flow, the roll designers usually modify their flower diagrams many times before they are satisfied that undue stresses will not be created between any of the passes. Different approaches to the flower design are described in Section 5.14.

Manually changing a flower diagram of a simple cross-section is easy. However, the more complex the section is, the more time consuming the change becomes. The roll designers are always under pressure and frequently behind schedule. Therefore, often the last flower changes are not completed, only noted as to what changes have to be made during roll design.

One of the big advantages of the computer-aided roll design is the speed of changing the flower diagrams. The roll designers can review many alternatives in a short time and select the one which appears to be the best under the given circumstances. Upon completion of the flower diagram, the roll design can commence from pass to pass.

5.11.2 Forming in the First Pass Rolls

The first pass rolls have multiple functions. They “pull” the leading edge of the strip into the mill and complete the first forming. In some cases, they also guide the strip and can score the material for sharp bending.

To pull the material into the mill is an important function. The maximum allowable forming angles at all passes, including the first one, depend on the thickness, mechanical properties of the material, roll diameter, length of the bent elements, lubrication, and the available top shaft drive. However, in the first pass, the maximum attainable angle often has to be reduced to suit the other functions, especially when feeding the strip into the rolls. If the forming angle is too large, then the operator may have to cut tapers on to two corners of the leading edge of the coils. Considering the thousands of coils processed through the mill, it is much less expensive to have the correct first pass rolls than have the mill standing idle while the corners of the coil ends are cut.

Some products, such as wide panels formed in the first pass at the center are usually guided into the mill by entry guides only. Ahead of the first pass of the center formed panel, a 6- to 12-in. (150- to 300-mm) long “hump” can be observed where the coil enters into the first pass center rolls. The length of this free floating “hump” fluctuates during forming. This length change is frequently associated with buckling in and out of the material which may show up as waves in the product. The forming can be

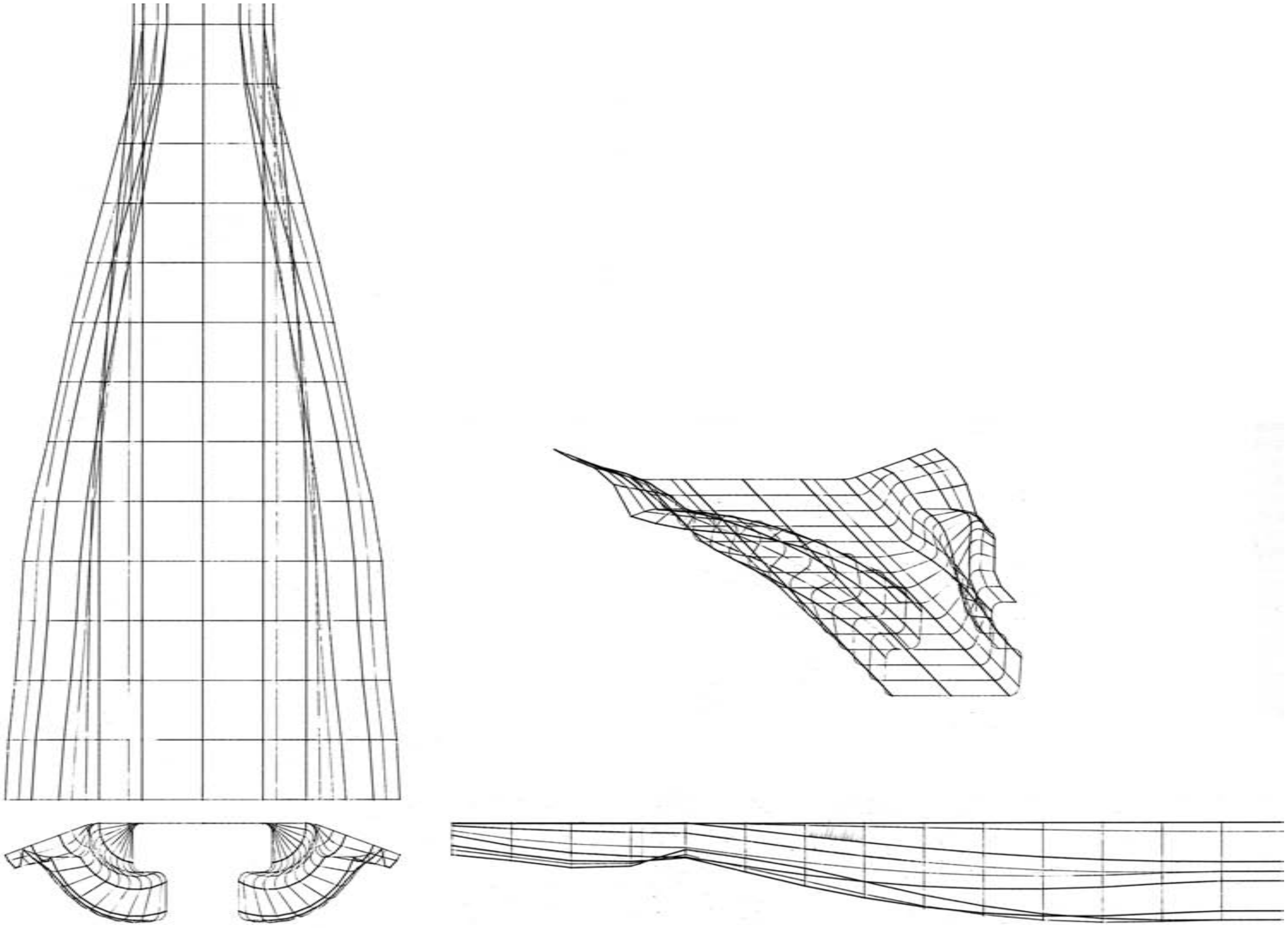


FIGURE 5.115 End, top, side, and three-dimensional views of the flower diagram. (Courtesy of Metform International Ltd.)

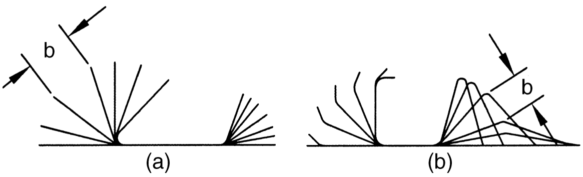


FIGURE 5.116 Big movements from pass to pass (b) creating high stresses should be avoided.

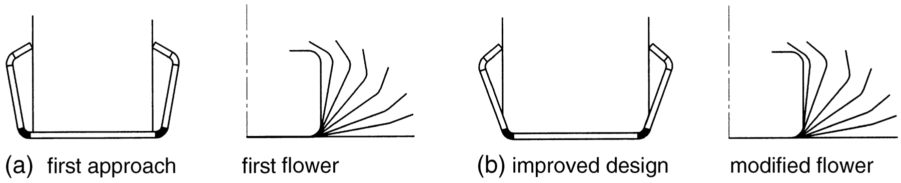

(a) first approach
first flower
(b) improved design
modified flower

FIGURE 5.117 Flower diagrams slightly changed allowing the top roll to reach the bend lines at Pass #7.

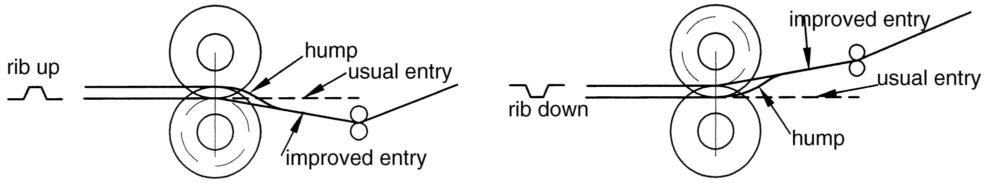
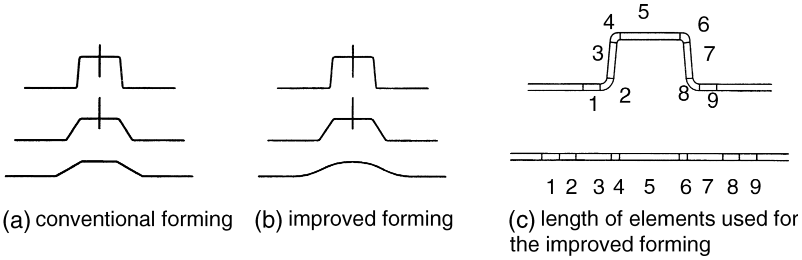


FIGURE 5.118 Modified entry angle can reduce buckle and waves at the first "rib" forming at the center of wide panel (elements 1, 5, and 9 are false bends).



(a) conventional forming
(b) improved forming
(c) length of elements used for the improved forming

FIGURE 5.119 Sinus wave-shaped false bending at the first pass reduces internal stresses at the first forming pass.

improved by placing a solid "hump guide" underneath the hump, which will keep the hump uniform. It is important that the two parallel entry rolls, frequently applied ahead of the entry guide, as well as the entry guide itself should be of sufficient distance from the first pass.

Forming of panels can often be improved or waviness avoided if the coil is fed in the first pass at an angle, up or down, to suit the natural formation of the "hump." For example, if the first corrugation is formed upwards, then it is frequently advantageous to lead the material from a lower or upper level up into the first pass at a shallow angle (5 to 15 in.) as shown in Figure 5.118. If the forming of the first rib is "up," then the lead from a lower level up is recommended and vice versa. Further help in forming can be achieved by using smooth "sine wave" first pass rolls (Figure 5.119b,c). The section can obtain its angular

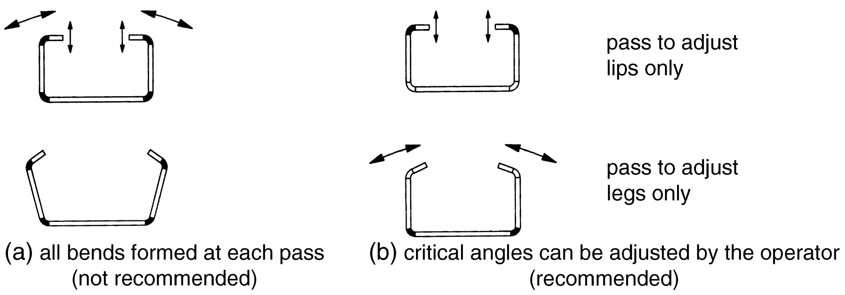

pass to adjust lips only
pass to adjust legs only
(a) all bends formed at each pass (not recommended)
(b) critical angles can be adjusted by the operator (recommended)

FIGURE 5.120 The roll designer should give opportunities to the operator to adjust critical angles one at a time.

shape in the next passes. Occasionally, the curved approach is used through several passes. Care should be taken to avoid permanent bending of the straight elements by selecting a suitable large $r:t$ ratio.

Narrow strips are usually guided at their edges by the first few pairs of rolls (see Figure 5.121). In this case, the entry guide is needed only to lead the strip in into the first two passes. Proper guiding of the strip by the rolls is also required when its surface is scored for sharp bending.

5.11.3 Forming in the Last Pass

To reduce the cost of tooling, in most cases, the final overbend for springback is accomplished in the last pass. The designer assumes that the product will springback and obtain its final shape after exiting this last pass. Better tolerances can be achieved if the last pass is a duplicate of the previous "final shape" pass. This last "duplicate" pass is frequently but incorrectly called the "ironing pass."

5.11.4 Adjusting Angles by the Operator

Regardless of how many bends are made in each pass, the designer should give a chance to the mill operator to easily adjust the critical angles. Figure 5.120 shows a split flower diagram. Bend lines marked in black indicate a change in the bend angle at that pass.

Flower diagram (Figure 5.120a) depicts a design where every bend line is formed at every pass. In this case, the operator adjusting the final angle of the lips by moving the top rolls up or down will inadvertently adjust the legs and vice versa. Flower diagram (Figure 5.120b) shows the correct approach. Moving the last pass rolls up and down will change the angle of the lips only. Adjusting the pass before the last one will modify the leg angles only.

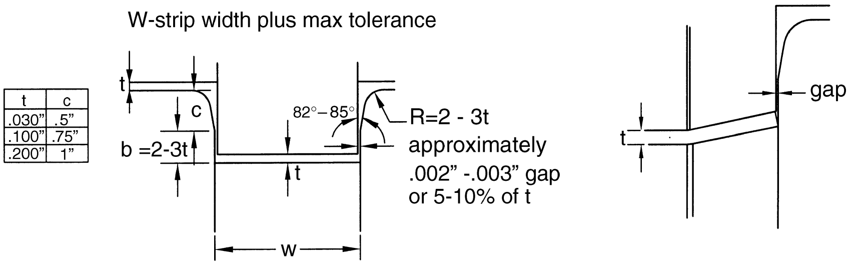
5.12 Roll Design

5.12.1 Strip Width Applied to Roll Design

The strip width used for roll design always represents the calculated strip width plus the maximum "plus" slitting tolerance. For example, if the calculated strip width is 2.000 in. and the strip width tolerance is ±0.005 in. (50.800 ± 0.127 mm), then the strip width used for roll design should be 2.005 in. (50.927 mm). For wide panels with large "runouts," the coil width used for roll design includes the added 0.5 to 1 in. (12 to 25 mm) runout at both sides or at one side only.

5.12.2 Traps

To avoid the strip "wandering" sideways between the top and bottom rolls and to obtain better tolerances, the strip is frequently trapped in the rolls. Because the strip width includes the "plus" slitting tolerance, the maximum movement of the strip to the left and right direction (wandering) between the traps will not exceed the total of the plus and minus slitting tolerances. For example, if the strip width is 3.000 ± 0.005 in.



t	c
.030"	.5"
.100"	.75"
.200"	1"

(a) vertical trap in the first pass (b) typical vertical trap at other passes

FIGURE 5.121 Vertical trap.

(76.2 ± 0.127 mm), then the maximum width between the traps will be 3.005 in. (76.327 mm). If the coil width happens to be 2.995 in. (76.037 mm), then the coil can be tight against one trap, leaving a 0.010-in. (0.25-mm) gap at the other side. This means that because of the strip width tolerance alone, in this case, one leg can be 0.010 in. (0.25 mm) shorter than the other.

Different kinds of traps are used to retain the strip edges in the rolls.

(a) *Vertical Trap.* A vertical trap (Figure 5.121a,b) is used when the strip ends are less than 15 to 20° to the horizontal. The vertical trap surface of the roll can be two to three times the material thickness, continued in an 82 to 85° lead angle and ending in a radius of a minimum two to four times the material thickness. The horizontal gap between the top and bottom rolls at the vertical trap is usually 0.002 to 0.003 in. (0.05 to 0.075 mm) or, for thicker materials, 5 to 10% of the thickness.

(b) *Angular Trap.* An angular trap is occasionally used for legs which are at approximately 30 to 60° angle to the horizontal. The application of the angular traps is limited because the sharp small trap is prone to damage (Figure 5.122).

(c) *Horizontal Trap.* A horizontal trap is applied to the strip edges over 40 to 60° to the horizontal. Normally, the steep legs of the section and the bend lines will provide sufficient guideline for the section, but a trap can still be used if the leg length tolerances are critical (Figure 5.123).

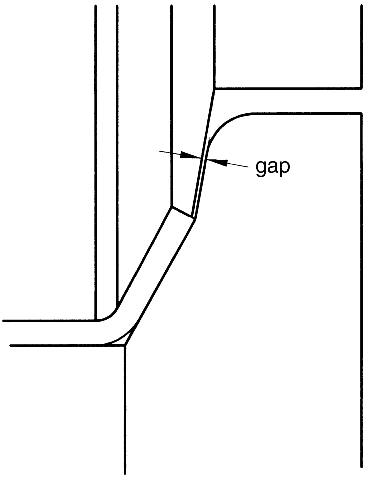


FIGURE 5.122 Angular trap.

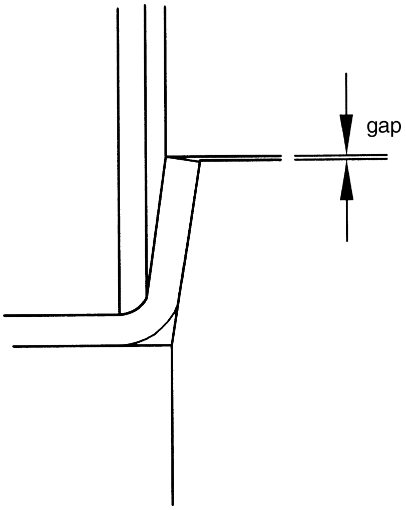


FIGURE 5.123 Horizontal trap.

(d) *No Traps*

- As mentioned above, for bends over 45 to 60°, traps are usually not required because the bend line will keep the section in track.
- Traps cannot be used if variable size products are to be formed without tool change (Figure 5.124). In these cases, it is advisable to guide the strip by the entry guide and by a few guides between the passes. The in-between pass guides should be adjustable in width and height.
- Wide building products with +3/16 in. (5 mm) coil width tolerance and with possible runout provisions are guided only by the entry guide.

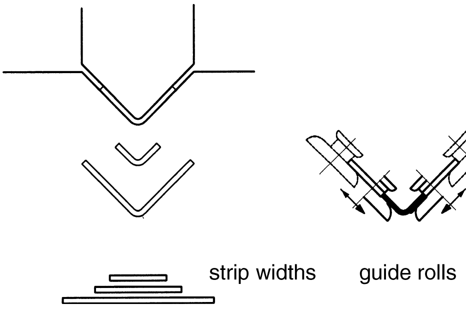


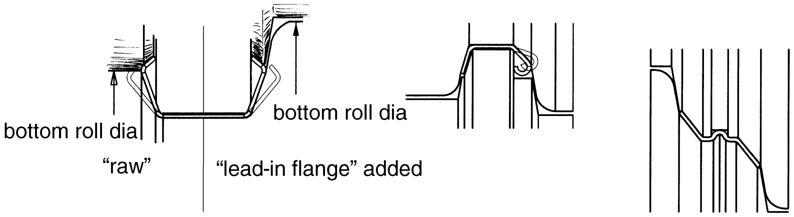
FIGURE 5.124 Angles with different leg lengths formed by the same rolls cannot be trapped (a). Guides adjustable in width and height are recommended between several passes.

5.12.3 Lead-In Flanges

"Raw rolls" designed by simply enveloping the cross-section would form the section but in most cases, it will be difficult, if not impossible, to enter the strip into the gap between the rolls. To help to lead the strip from one pass into the next pass, it is advisable to change the "raw" rolls by adding "lead-in flange" sections to them (Figure 5.125 and Figure 5.167).

Lead-in flanges, which often include traps, are more critical when forming sections with critical surface finish, high strength/high springback material, very thin material or forming noncontinuous strip precut blanks or strips with holes or notches. Leads are not required when section bending commences at the center part of the strip, and when the edges are not formed up or down as in the forming of wide panels and similar products.

The lead-in flange design is based on the geometry of the strip edge, its direction (up or down), and the degree of bending at that pass. It is usually designed to have the outside edge of the strip (section) contact the lead surface as it exits from the previous pass. The left side of Figure 5.125 shows the "raw" roll design (without lead-in flange). The strip coming from the previous pass would hit the edge of the roll, creating surface marks and extensive roll wear. The right-hand side of the same pass shows the bottom roll with a "lead" surface. The strip edge will contact the lead surface and will travel more gently to its new position, creating less internal stress. Longer lead in will reduce the stress and will less likely create waviness, flare, or other deviations form straightness and flatness (Figure 5.126).



(a) leading up added at the right side (b) lead down (c) left side lead up, right side lead down

FIGURE 5.125 Unedited (raw) rolls at the left side and edited (with lead-in flange) at the right side of rolls. The thinner line represents the cross-section formed at the previous pass (a); (b) shows both sides lead-down and in (c), the left side is lead-up while the right side lead-down.

Depending on the direction of the strip edge movement (up or down), the lead is placed either on the bottom or on the top roll. The roll on which the lead is placed by its rotating movement will, in almost all cases, move the strip edge away from the shaft as shown in Figure 5.127. The direction of the roll rotation (friction on the roll surface) helps to move the strip into the roll gap.

(a) *Lead-In Flange Design for Straight Edge.* The approximate edge travel (Figure 5.128) in the horizontal direction is between passes:

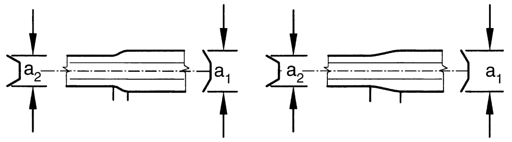
ET 1 to 2 $= L(\cos \alpha_1 - \cos \alpha_2)$ (edge travel between Pass 1 and Pass 2)

ET 6 to 7 $= L(\cos \alpha_6 - \cos \alpha_7)$ (edge travel between Pass 6 and Pass 7)

The increase in roll diameter to accommodate the lead-in flange depends on the horizontal travel of the edge from the previous pass, material thickness, roll diameter, springback, and other factors. Figure 5.129a,b shows that as leg entry angle increases, for the same angle increment between passes the guide roll diameter has to be increased.

Occasionally, the lead angle is an extension of the forming angle, as shown in Figure 5.130.

A part of the radius at the roll edge of the lead and horizontal roll surface intersection can often be used to start to lead the edge of the strip. A large radius tangent to the lead surface only (Figure 5.131a) is more practical than a smaller radius tangential to both surfaces (Figure 5.131b). A frequently used lead surface has about two-thirds straight and one-third large radius surface. Occasionally, it can be necessary to have a lead radius that intrudes into the straight portion of the section particularly when forming to the vertical.



(a) using short flanges (b) using long flanges

FIGURE 5.126 Long lead creates lower stresses in the product.

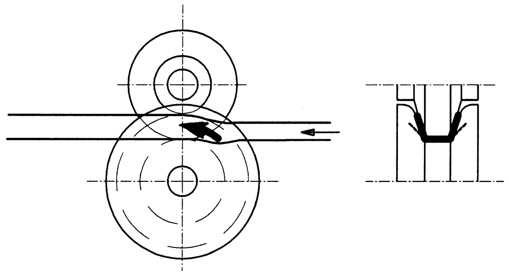


FIGURE 5.127 Friction at the lead-in flange surface helps to move the legs in the right direction.

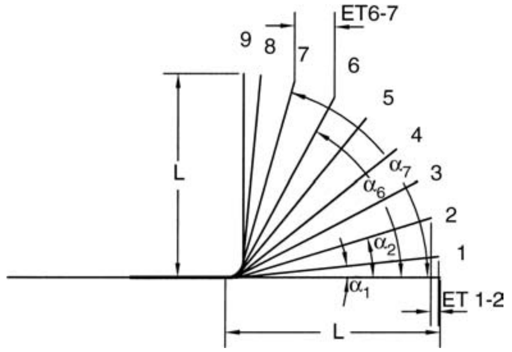
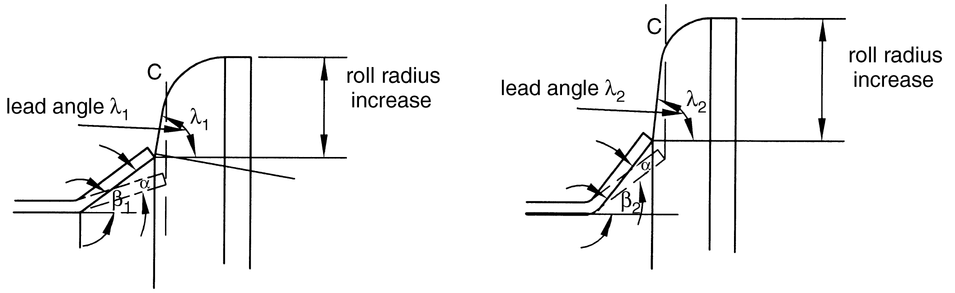


FIGURE 5.128 Edge travel in the horizontal direction between passes.



(a) Roll diameter increase at shallow angle (β_1) (b) Roll diameter increase at steeper angle (β_2)

FIGURE 5.129 Formed angles (α and β) influence the roll diameter increase required for the lead-in flange.

(b) *Lead-In Flange Design for Curved Edges.* If the furthermost edge of the section is already formed, then the lead-in surface may start from a tangent point to the outermost element (Figure 5.132). This method is frequently used when the lead is also used to "push" the leg inwards, especially when forming a blind corner.

If the lips are already formed and the roll opposite to the roll with the lead-in flange cannot reach into the bend line, then those rolls can be relieved as shown in Figure 5.133a. However, if the bend line to be formed is a "blind corner" (Figure 5.133b), then it is more prudent to "contain" (box in) the section by pressing down the lips (Figure 5.133c).

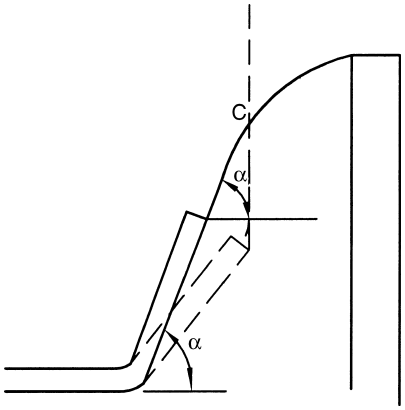
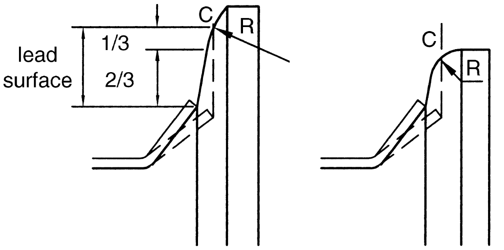


FIGURE 5.130 Occasionally, the extension of the forming angle can serve as a lead-in.



(a) Large lead radius tangent to lead surface only (better)

(b) Smaller lead radius tangent to both surfaces

FIGURE 5.131 Part of the radius at the end of the lead surface can be used for lead. Large radius tangent to one surface (a) is better than smaller radius tangent to two surfaces.

The diameter increase caused by the lead in both the "trap" and "lead" rolls makes it frequently more economical to split the rolls as shown in Figure 5.134. The split lines on the drawings are indicated with triangles. This splitting allows the rolls marked T1, T3, and B2 to be made from smaller diameter blanks, saving in material cost. This arrangement also makes rework, adjustment, or replacement easier and less expensive. Furthermore, splitting makes it easier to adjust or replace rolls if the blank size has to be modified.

(c) *Lead-In Flange is not Required.* Lead-in flanges are often not required when the bending of the section commences at the center part of the strip, not at the edges, such as forming of wide panels and similar products with relatively loose tolerance on the lips (last elements at the edges).

Typical examples are shown in Figure 5.135a–c. Because building panel rolls do not require lead surfaces, the roll diameters do not have to be increased.

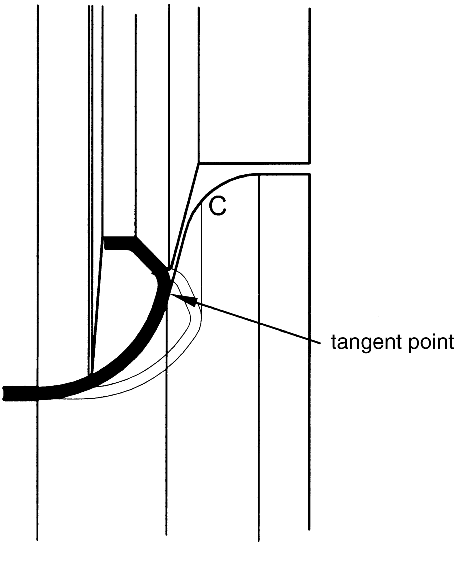
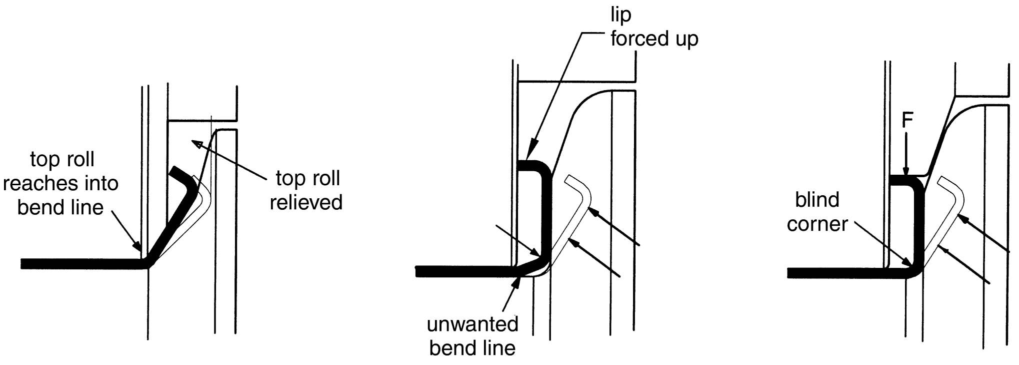


FIGURE 5.132 Lead can be tangential to the outermost curved surface.



(a) Top roll can be relieved if strip edge is already formed

(b) Blind corner forming without retaining strip edge (lip)

(c) Forcing lip down provides better section

FIGURE 5.133 When male roll does not reaches the bend line (blind corner), then it is recommended to force the edge (lip) down to avoid unwanted deformation.

Traps or leads are frequently omitted for certain types of forming, especially over a 40 to 50° angle. However, lead-in flange may be incorporated occasionally even at these angles when the edge of the strip has to be pushed inwards or downwards when forming blind corners (Figure 5.136a). In case of blind corners, the application of cluster-rolls is sometimes more effective than the lead-in flanges (Figure 5.136b).

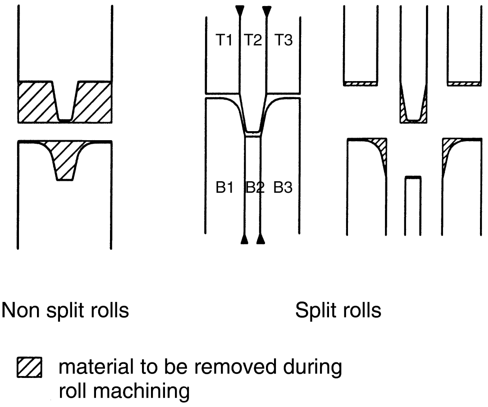


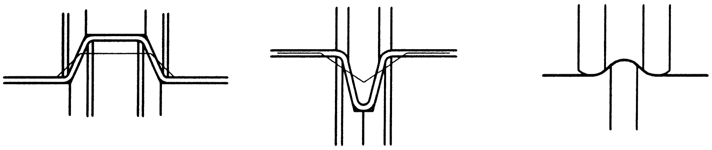
FIGURE 5.134 Rolls are split by necessity as well as to reduce tool material cost.

5.12.4 Finalizing Roll Edge Radii at Bend Lines

Two alternatives are available to finalize the radii at the convex and concave part of the rolls at the bend lines.

(a) *Matching Radii on Both Top and Bottom Rolls.* Many rolls are designed to fully envelope (surround) the section at each bend line (Figure 5.137a). The rolls are machined to have their forming radii identical to the inside and outside bend-line radii of the section. Rolls designed in this way have to be turned and set up with more care; small discrepancies can create problems at the bend-lines.

(b) *Radii on the Convex Rolls Only.* During forming, the strip is wrapped around the male die and the bend lines will be thinner. The outside of the strip at the bend line may not even touch the

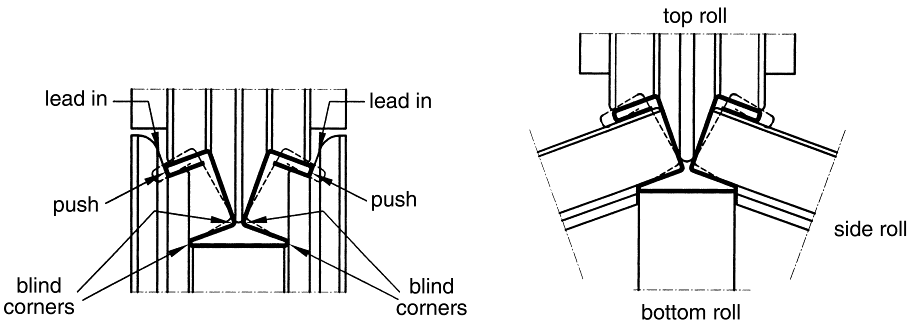


(a) Building panel

(b) "T" section

(c) Corrugated section

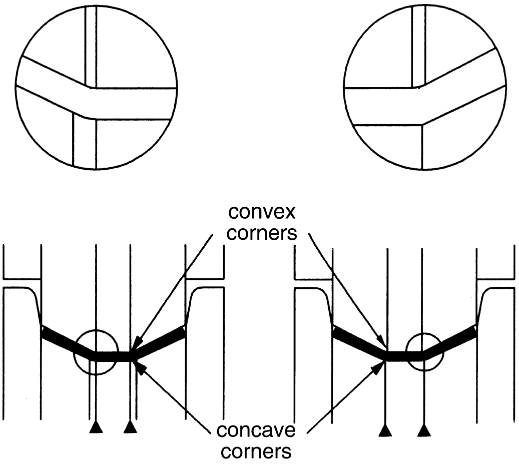
FIGURE 5.135 Lead-in flanges are not required when forming at the center of section, away from the edge.



(a) Top and bottom rolls only

(b) Cluster rolls can be more efficient

FIGURE 5.136 Lead-in flanges are required when it is prudent to "push" the strip inwards (a) to help forming. In some cases, side-rolls or cluster-rolls would be more efficient (b).



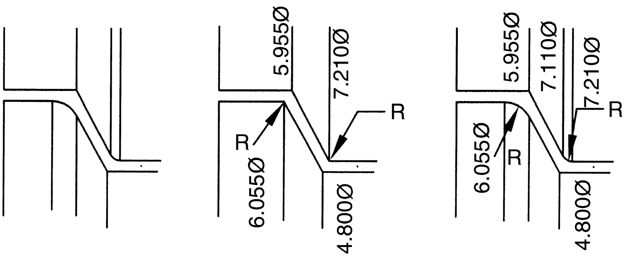
(a) With radius

(b) To tangent point

FIGURE 5.137 Concave corners of the rolls are frequently cut to the tangent points.

bend line radii on the female rolls. Therefore, the concave rolls are frequently machined to the tangent point at each bend line. Rolls designed to tangent points can be more easily split (Figure 5.137b) and turned easily manually. Most manual lathe operators prefer drawings showing tangents point with an indication of the radii required for the corners (Figure 5.138).

The effect of the two different roll designs (all rolls with radii or convex rolls to tangent point only) on the final product is not clear. The author assumes that because of the small roll misalignments in the mill, the "all rolls with radii" will apply some "cold forming" to the corners, thus reducing springback. Rolls turned to their tangent point are more "forgiving" to similar misalignments (Figure 5.139). However, if the edges are trapped or pushed, then radii of both rolls will provide a better radii control to the finished section. If the straight element adjacent to a radius is forced towards the curved element (across the strip), then it is possible that the strip "moves



(a) Finished rolls

(b) Drawing for manual or NC turning

(c) Drawing for NC turning

FIGURE 5.138 In the case of manual turning, the lathe operators prefer drawings showing tangent points.

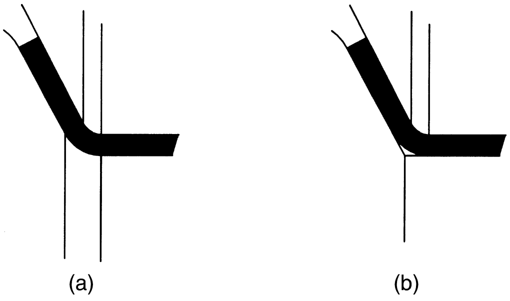


FIGURE 5.139 Both top and bottom rolls with corner radii (a) require more careful alignment along the mill than rolls with concave corners machined to tangent points (b).

away" from the male roll. This movement can result in a sharper than intended corner radius (Figure 5.140).

If concave rolls are not split at the tangent point, then the application of a small radius is recommended, especially for rolls with thin wall flanges exposed to large side pressure (Figure 5.141). Sharp corners are potential starting points for cracks.

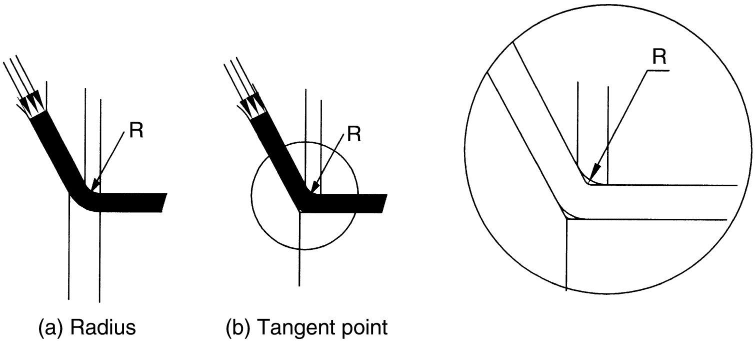


FIGURE 5.140 The trap forcing down strip edge into the corner may deform the radius if the concave roll is machined to the tangent point.

(c) *Bending Radii on Overbending Rolls.* Following the "constant arc length" theory, whenever a bend line is "overbent," then the bend radius will become smaller. Although some roll designers ignore this fact because the change in radius is small, it is proper to apply the correct radius (Figure 5.142). The correct radius can be calculated with the equation used for constant arc length bending (Equation 5.15) or by the proper software.

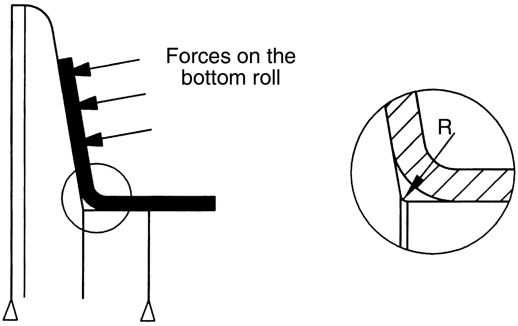


FIGURE 5.141 Leave a small radius at the tangent point of the concave rolls to avoid roll edge cracking.

5.12.5 Applying Additional Radii to the Rolls

(a) *Radii on Split Rolls and Rolls Ending with a Flat Surface.* The radius at the edge of a split roll should be sufficiently large to minimize marking of the product. Marking can be caused by the slight differences in the mating roll diameters, out of roundness, out of center, too big gap between roll bore and shaft diameter (Figure 5.143).

Rolls that have to be split at a tapered part of a section, because they are used for a variety of purposes or because of their weight, may require large radii at the sharp edges to avoid damage to the rolls and marking of the product (see Figure 5.144, right-hand side).

(b) *Other Roll Edge Radii.* Applying a small radius to all sharp edges is recommended for safe roll handling and to minimize edge damages. (A general note, e.g., "brake corner" 0.030 in. [0.75 mm] *R* can be an instruction on all roll drawings).

To avoid chipping of very sharp, shallow angle edges, a radius may have to be included on rolls which otherwise do not require radii. However, if the roll is already made with a sharp tip, the tip cannot be remachined without reducing the material required to achieve the final height. In this and similar cases, it is recommended to change the roll design and apply additional false bends adjacent to the final radius (see Section 5.9.6 and Figure 5.97b and Figure 5.144). The arc of the final radius plus the two false bends will provide a larger radius at the tip of the roll at each pass. Eventually, the arcs of the false bends will be flattened at the last pass. The section will have the correct shape, height, and will less likely split (crack) at the 180° bend.

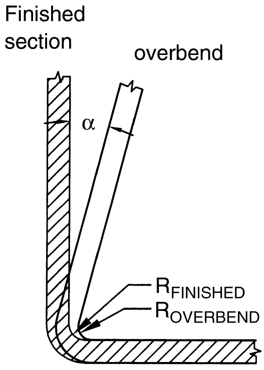


FIGURE 5.142 Use the correct radius for overbending; the radius at overbending is smaller than the finished radius.

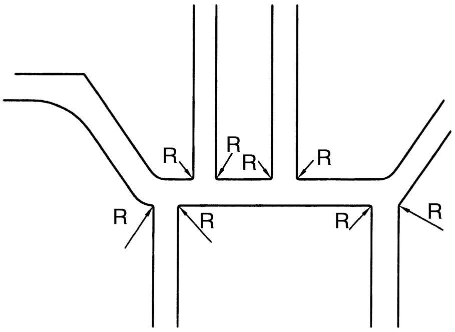
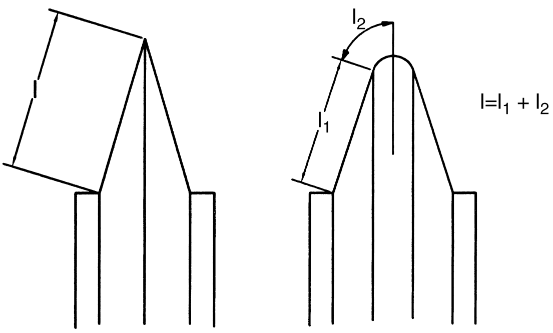


FIGURE 5.143 Small radius (*r*) should be placed at each split roll edge to avoid marking of the product and damage to the rolls.



(a) Original roll shape (b) Improved roll shape

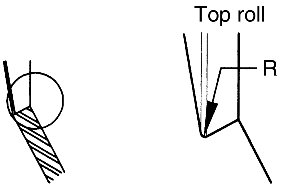
FIGURE 5.144 To avoid sharp tips on rolls, the roll design can be modified by using false bends.

Designs incorporating traps can leave very sharp roll edges. These edges can be easily damaged. It is recommended to either avoid them or add a small radius to them (Figure 5.145a).

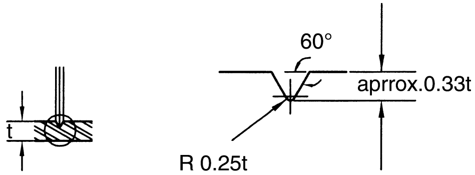
A small radius is recommended at the peak of the scoring (grooving) rolls used when the product must be formed with sharp inside radius (Figure 5.145b).

For rolls forming sine wave corrugations, a different kind of radius is recommended. The sinusoidal shape is usually "air bent" and the roll designer specifies the required radius to be incorporated onto the outer edges of the "donut" shaped rolls. This method works correctly in most cases (Figure 5.146a). However, to reduce springback the forming depth may be increased by lowering the top shafts. If the rolls are pushed deeper in between each other, the material is no longer tangential to the rolls. This can create unacceptable sharp forming lines adjacent to the radii in the panels (Figure 5.146b). To avoid the sharp lines, it is recommended to place additional radii at the edges of the rolls, tangential to both the large forming surface and the flat ends of the roll (Figure 5.146c).

(c) *Bore Radii.* A sharp edge in the bore of the rolls can damage the shafts and make installation difficult. Therefore, it is recommended to specify a small radius at both ends of the bores. The radius can be 0.030 to 0.060 in. (0.75 to 1.5 mm) in rolls up to 10 in. (250 mm) in diameter. Too large bore radius can create problems because of the reduced contact area between the rolls and the spacers or shaft shoulders (see Section 5.7.2).



(a) Trap or lead-in



(b) Scoring the strip

FIGURE 5.145 To avoid "chipping" of roll edges, applying a small radius is suggested at the critical points.

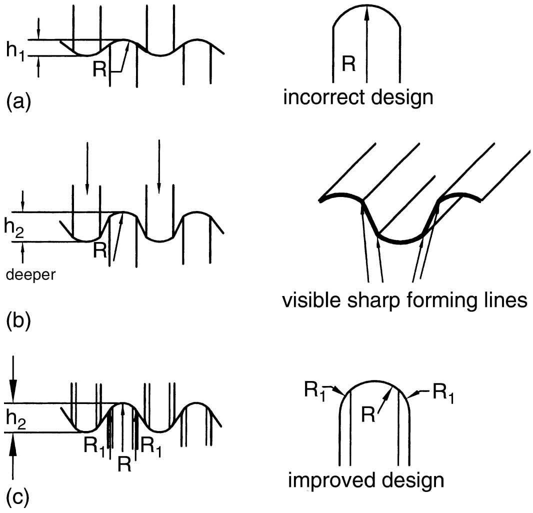


FIGURE 5.146 A single radius at the working surface of the donut-shape rolls (a) can mark product (b). Added corner radii eliminate this problem (c).

5.12.6 Relief

The inevitable surface speed differential along the contour of each roll, caused by the different roll diameters (Figure 5.147), create many problems. Different diameter roll segments forming or just contacting either side of the strip surface will create friction, may mark the surface of the product, wear the rolls, make the product speed uneven and increase the torque (horsepower) requirement for forming.

To minimize the friction, the rolls are often designed with a "relief." The example shown on Figure 5.148 shows the top roll relieved by 2 to 3°. This change eliminates the friction between the top roll and the product, and by driving the product at the peak of the section provides a more positive and even drive at the pass line height.

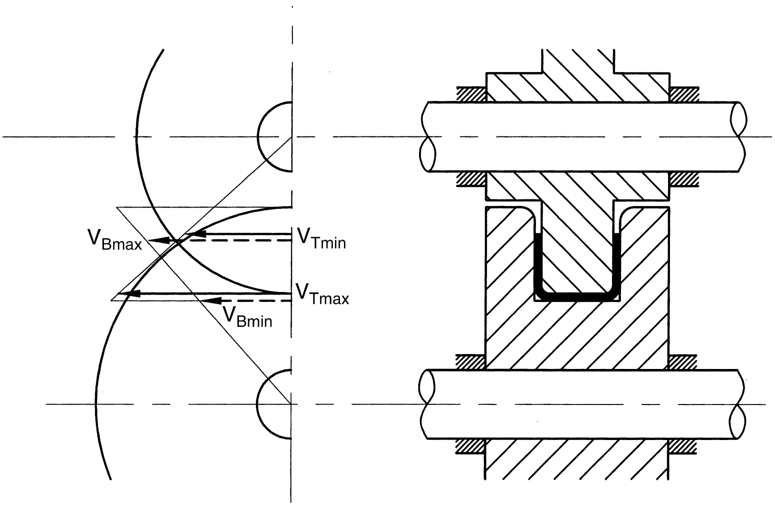
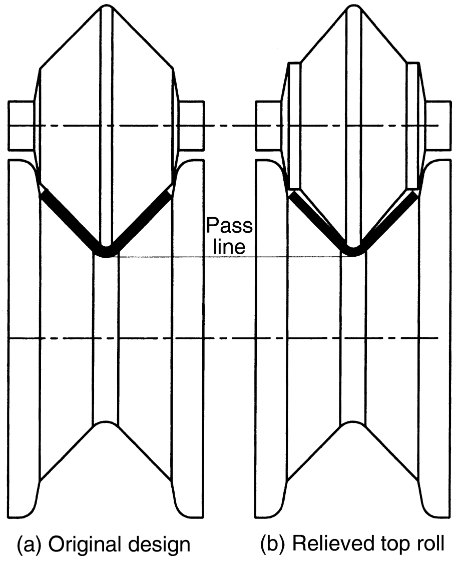


FIGURE 5.147 Surface speed differential exists at every diameter in contact with the material, except at the pass line.



(a) Original design (b) Relieved top roll

FIGURE 5.148 The original top rolls are "rubbing" against the section at different speeds at full contact line (a). Relieve top rolls (b) are in contact only at one point with the material, running at the same speed.

Similar relief is recommended at blind corner rolls as shown on the right-hand side of a roll in Figure 5.149. The extensive rubbing action between the section edge and the roll (Figure 5.149a) will be reduced by the relief to a short distance (Figure 5.149b).

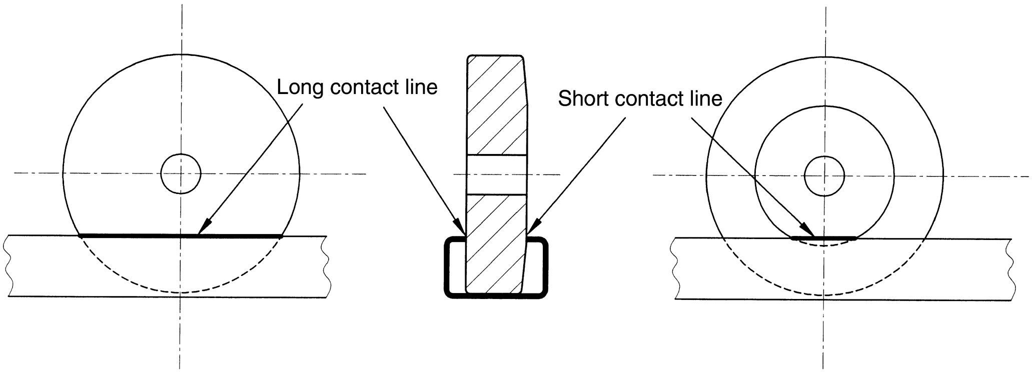
The application of similar relief is recommended for panel rolls (Figure 5.150). It will have the same beneficial effects mentioned above without changing the section dimensions. A similar but deeper and parallel cutout is used to provide space for embossed composite deck webs (Figure 5.151).

Because this type of roll relief works, then the application of disk rolls (Figure 5.152), utilized by several designers, should also work. Cautious designers may place full (not relieved) rolls in passes in which grooves are stretched into the panel to avoid slipping off the bend lines. Full rolls are usually used at the last passes.

5.12.7 Interlocking

Interlocking or "gating" keeps the top and bottom rolls aligned in the horizontal direction and it is highly recommended. Interlocking requires extra roll material but it saves a considerable amount of setup time, reduces scrap and eliminates some of the troubleshooting requirements.

Typical interlocks (occasionally called "locks" or "gates") are shown in Figure 5.153. After the rolls are placed on the shafts and the operator sets the gap at both ends of the rolls, the rolls are properly set. The gap at both ends of the rolls at all passes should be equal to the material thickness gap between the rolls. However, a few plants prefer to have a "standard" gap at the interlocks for all tooling. For example,

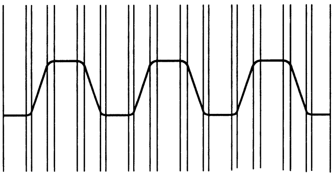


(a) Not relieved (b) Relieved

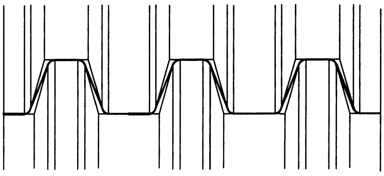
FIGURE 5.149 Relief reduces the contact area between the roll and the section.

a 0.100 in. (2.5 mm) gap at the both ends of the rolls at each pass sets all the rolls in this set to the proper, say, 0.020 in. (0.5 mm) roll gap.

The interlock can go up or down at both ends of the rolls at any pass, but should not go up at one end and down at the other end at one pass. The interlock direction is usually dictated by economy. If the rolls on one shaft are "forced apart" during forming, then some designers incorrectly plan to keep them together by the rolls on the other shaft, especially if the female roll is not split. This is not a good practice because the top and bottom rolls should never touch each other. Occasionally, when forming is not forcing split rolls apart, only the bottom rolls will have spacers and the top rolls will be positioned by the "locks" ("gates") before material enters between them. Once the material is between the rolls, it will "self position" the rolls installed on the other shaft without spacers.



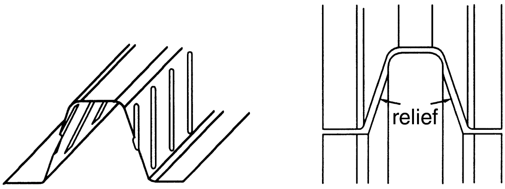
(a) Original rolls



(b) Relieved panel forming rolls

FIGURE 5.150 Relieved panel rolls reduce friction, pick-up and horsepower requirements.

The width of the interlock ("*w*") is determined by its strength required in case of unexpected problems. The interlock should always be conveniently wide, approximately 0.5 in. (12 mm), to permit the insertion of a feeler gauge horizontally. The height of the interlock ("*h*") is less critical, it should be at least 0.4 to 0.6 in. (10 to 15 mm) to facilitate installation. It is advisable to have a small taper or radius at the opposite mating corners (Figure 5.154) to assist the installation of the interlocking surfaces during setup.



Embossed composite Rolls relieved for embossment

FIGURE 5.151 Forming rolls relieved to accommodate composite deck embossments.

The 0.002 to 0.003 in. (0.05 to 0.075 mm) gap (marked "*b*" in Figure 5.153 and Figure 5.154) should be checked after each setup with a mirror. The interlocking surfaces should never touch each other; they are there to help setup only. To avoid the contact between the interlocking surfaces, it is better to have all the usual spacers in both top and bottom shafts.

5.12.8 End Gap

The horizontal surfaces at both ends of each pass of rolls can greatly help the setup procedure. The end gaps, explained above in the interlock section, can be applied to all roll sets even if they are not supplied interlocked. End gaps may require some extra roll material and more precise machining of the rolls, but it will be a substantial setup time saver during the life of the rolls.

5.12.9 Roll Length

(a) *Narrow Sections.* The roll length at the first pass is calculated as the strip width plus roll material required for trap or lead in flange surfaces at both ends. The figure is usually rounded up to the nearest 0.25 to 0.5 in. (5 to 10 mm). As forming progresses and the section narrows, designers frequently reduce the roll length to save roll material. This reduction is economical, but the simplicity in setup and checking should also be considered.

For example, the simplest way to check the vertical alignment of the top and bottom shoulders as well as the roll alignments is to place a short straight edge (ruler) to the ends of the rolls at the operator side (Figure 5.155). If they are aligned, then the shoulders and the rolls are most probably aligned properly. To accommodate this simple checking, both top and bottom rolls in a pass shall have the same total length within 0.0005 in. (0.125 mm).

The alignment in the longitudinal direction can also be simply checked by placing a straight edge to the outside surface of the rolls (Figure 5.156). One or two length reductions in 10 to 12 passes can be made, but the change should be in round figures such as 0.5 or 1 in. (10, 20, or 30 mm) at each side. This will allow the placement of the straight edge against the first several passes and the next two or three passes can be checked with an additional 0.5- or 1-in. wide gauge block (Figure 5.157). Once a few

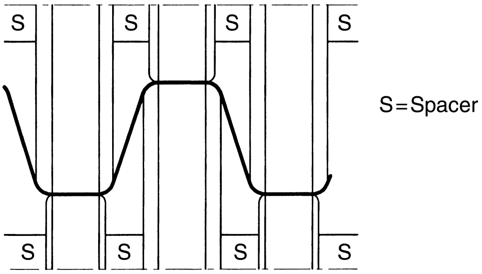
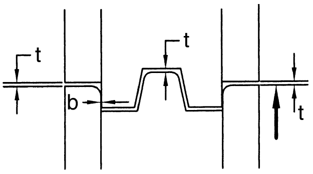
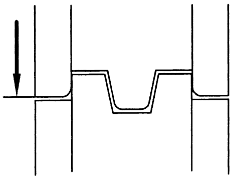


FIGURE 5.152 Disk rolls are used to form panels by some designers.



(a) lock up



(b) lock down

FIGURE 5.153 Interlocking aligns top and bottom rolls. Gap and parallelness can be easily set at both sides.

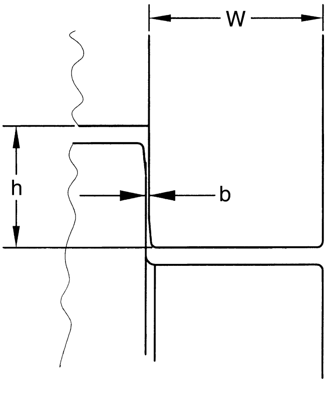


FIGURE 5.154 Small taper at both top and bottom lock helps roll installation.

passes of the shorter rolls are checked, then the straight edge can be moved over to these and so on.

It is highly recommended not to make the top and bottom rolls to different lengths or to reduce the roll length in every two or three passes to save tooling cost. The little extra cost will be paid back many times by the ease of setup and checking.

(b) *Adjustable Roll Lengths.* Multiple-purpose rolls used to form products with variable widths or other dimensions may consist of complete set of rolls or mixtures of rolls and spacers. In both cases, the location of the rolls and the section dimensions are changed by relocating rolls or spacers.

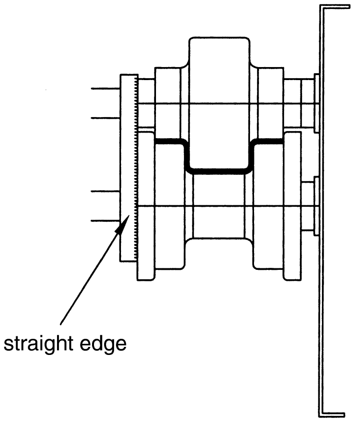


FIGURE 5.155 Vertical alignment of rolls can be easily checked with a small straight edge if roll lengths are the same within 0.0005 in. (0.01 mm).

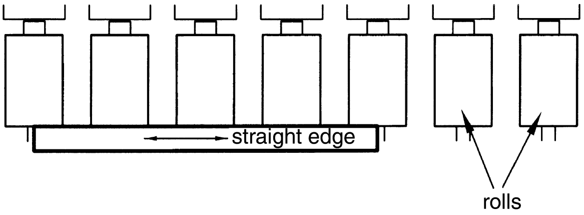


FIGURE 5.156 It is easy to check the shoulder misalignment in the longitudinal direction with a straight edge if all rolls are the same lengths.

(c) *Wide Sections.* Experience indicates that when forming wide sections, not all passes require a complete set of top and bottom rolls. Figure 5.158, Figure 5.77, and Figure 5.100f show a typical panel rolling mill. The forming starts at the middle and after a few passes, the adjacent corrugations (cells) are formed. In the first pass, only the center rolls are used, the rest of the roll space is filled with spacers. Occasionally, some supporting (not forming) rolls are used to guide the flat part of the panel close the edges. Some setup technicians prefer to have these supporting rolls mounted on the spacers with set screws. This will allow them to be moved to the right location during testing of the roll set.

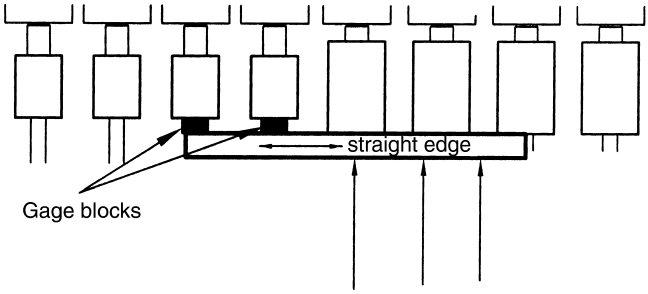


FIGURE 5.157 To save 1 to 2 in. (25 to 50 mm) or more of roll material, a one or two length reduction may be made.

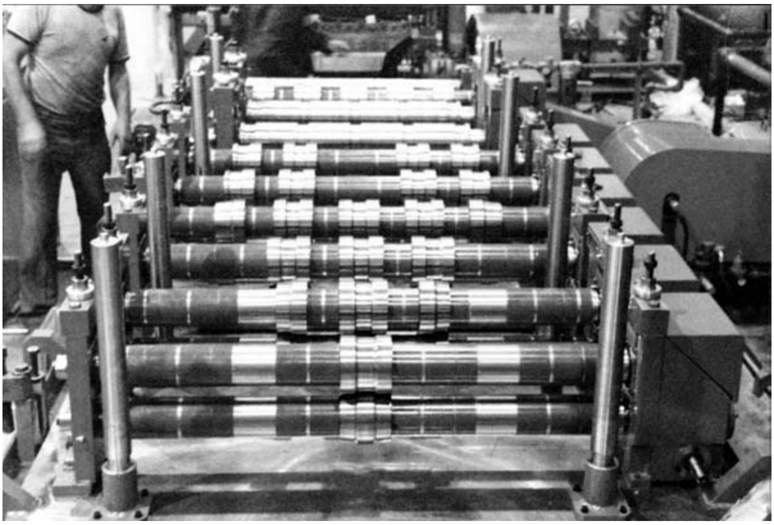


FIGURE 5.158 In panel mills, most passes do not require full set of rolls.

As forming continues away from center, closer to the edges, several center rolls can be deleted with the exception of the top and bottom guide rolls for one cell at each or at every second pass.

Complete sets of top and bottom rolls, which fully envelop the section, are only supplied for the last two passes. The above described principle can eliminate 25 to 45% of the rolls by replacing them with lower priced spacers.

5.12.10 Scoring (Grooving) Rolls

The recommended design for scoring rolls is mentioned in Section 5.6.2 (Splitting) and Section 5.12.5 (Application of Radii).

5.12.11 Cutouts for Embossments and Other Protrusions

Embossments or grooves are frequently formed in the first passes. To ensure that these protrusions from flat surface are not "squashed back," the rolls in the subsequent passes have to be cut away. It is suggested that the cutouts should be longer than the shape of the protrusion. If the cutout has the same size as the protrusion, a slight deviation in shoulder alignment or setup will reform the longitudinal grooves or squash the embossments. Because the protrusions are already formed, it is better to use oversized cutouts, not touching the protrusions (Figure 5.159).

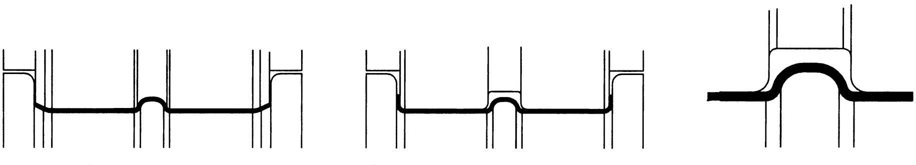


FIGURE 5.159 Passes following the forming of grooves require generous cutouts to prevent the reforming or damaging the grooves.

5.12.12 Overbending

Metals roll formed at room temperature will display "springback" (Figure 5.160). To obtain the angle specified on the drawing (α), the section must be overbent by more or less the same degree as the springback. The amount of springback is influenced by many factors (see also Section 5.4.3). The springback and thus the angle of overbending will increase if:

- The yield strength and the tensile strength of the material is higher
- The elastic modulus (E) is lower
- The $r:t$ ratio is larger
- The gap between the male and female rolls is raised
- The bending angle is below certain limit (small angle bending)

Because the springback can vary from coil to coil and even within a coil, the degree of overbending by the rolls should be adjustable.

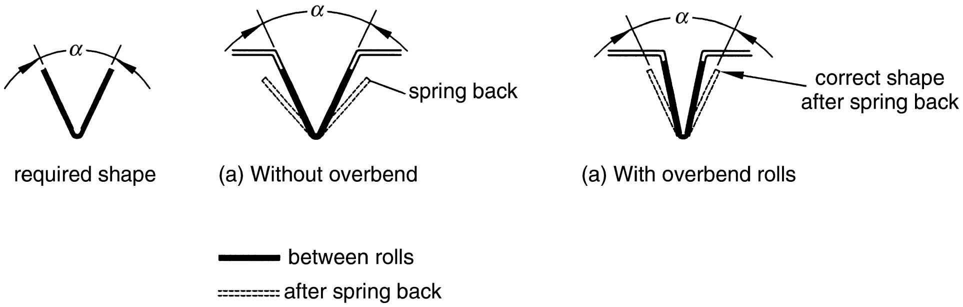


FIGURE 5.160 Overbending is required to counteract springback and to achieve the required bending angle.

Some of the frequently used overbending methods and rolls are shown in Figure 5.161a–i.

- Figure 5.161a is a simple method of overbending used when a relatively small springback angle is predictable. Springback adjustability is minimal.
- Figure 5.161b is a typical arrangement for overbending with side-rolls. This method can be applied to a wide variety of finished angles but the maximum angle is limited by the possible chipping or breaking of the too-thin male roll.

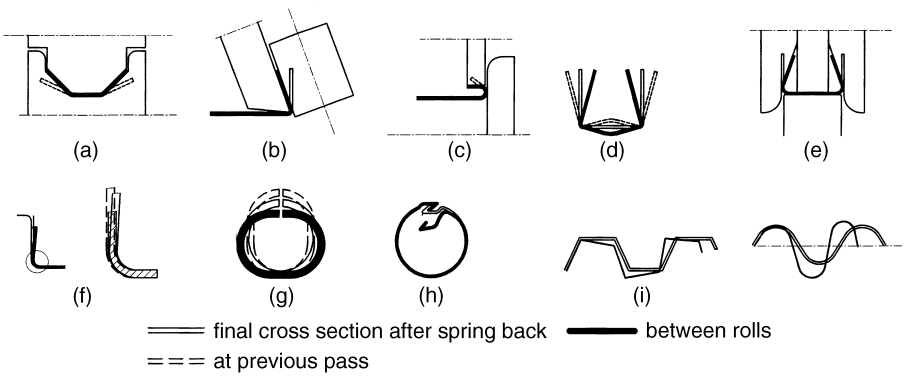


FIGURE 5.161 Different overbending methods can be used.

- For hems (fold-back), the degree of overbending can be adjusted by lifting or lowering the top rolls (see Figure 5.161c). This method can be applied from an angle of approximately 120° (depending on leg length) to bending over 180° (teardrop shape).
- Figure 5.161d shows how overbending can compensate for springback by utilizing a false bend. This is a relatively flexible method and is applicable to any angle including partially closed sections.
- Figure 5.161e, one of the oldest (and still frequently used) methods, is overbending angles with tapered rolls. Adjusting the rolls up and down will change the degree of overbend, but considerable up and down movement is required when the springback variation is large. It is more frequently used to overbend predictable small springback. This method is applicable to bends between 90 and 180°.
- Figure 5.161f — after forming a 90° angle, a small "constant radius" bend adjacent to the 90° bend can provide an overbend. A small up and down movement of the upper roll can change the overbend angle. It is assumed that after springback, the product will have the correct angle and the right width. According to an experienced roll former [414], this method helps to reduce flare too.
- Springback in nonwelded tubes will create a larger than the desired slot. The slot can be closed by forming a vertical oval at a previous pass followed by an overbend roll producing a slightly oval section in the horizontal direction (Figure 5.161g). After springback, the section will be circular with a small or no gap between the edges.
- Figure 5.161h — one edge of a tubular section to be lock-seamed can be overbent towards the tube center to achieve the required overlap for lock-seaming. After springback, the lock-seam process can be completed.
- Figure 5.161i — the outside corrugations, close to the edge of roll formed panels made from high strength material, will have considerable springback. The result is shallower edge corrugations and wider panel than required. To compensate for springback, some of the outside bend lines can be overbent by a few degrees (depending on the material). The springback of these overbent angles will yield the correct cross-section.

5.13 Calculating Roll Dimensions Manually

The flower diagram shows the cross-section of the partially formed strip at each pass. To start the roll design, the designer has to calculate the geometry of both the top and bottom surfaces of the strip and establish top and bottom roll pass diameters at each of the passes.

The roll geometry calculations are similar to the calculation used to establish strip width. The main difference is that the roll geometry has to be established for both top and bottom roll surfaces at each pass including side-roll passes.

Every roll designer has a slightly different approach to the calculations, which are sometimes augmented or shortcut by making drawings in large, usually a 10:1 scale.

The following example shows one method of calculation of a "hat" section shown in Figure 5.162. In Figure 5.162a, the drawing shows the finished hat section, Figure 5.162b shows half of the cross-section with straight and curved element numbers starting at the centerline (vertical guide plane). Figure 5.162c shows the length of the straight elements. The inside radius and thickness are assumed to be 0.200 in. Figure 5.162d shows the flower diagram using 6 passes. Note that this example is designed for demonstration purposes only and does not reflect the optimum forming angles.

(a) *Blank Size (Strip Width) Calculation*:

Element #2 (and #4) use Equation 5.7

$$L = 0.0174533 \times 90(0.2 + 0.33 \times 0.2)$$

$$L = 1.570797 \times 0.266 = 0.4178$$

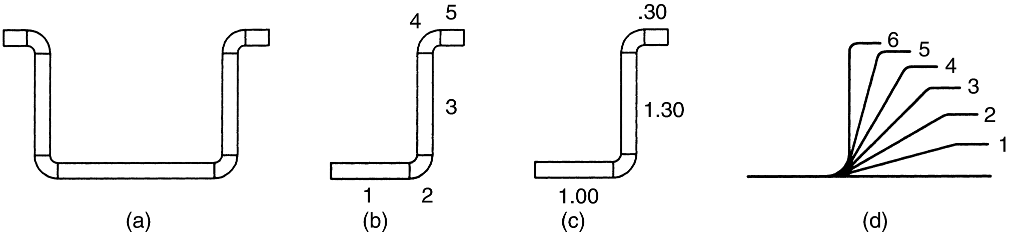


FIGURE 5.162 Finished section is broken down to straight and curved elements.

$t = .20$	6 passes	α_1 (15°) 15°
$k = .33$		α_2 (15°) 30°
$R = .20$		α_3 (15°) 45°
		α_4 (15°) 60°
		α_5 (15°) 75°
		α_6 (15°) 90°

Element #	
1	1.0000 (straight)
2	0.4178
3	1.3000 (straight)
4	0.4178
5	0.300 (straight)

(b) *Calculating Bending Radius for Constant Arc Bending* (use Equation 5.15)

For simplicity, only Pass # 2, Pass # 4, and Pass # 6 are calculated.

For Pass # 2, $\alpha = 30°$ $R_2 = (180/\pi)(.4178/30) - (0.33 \times 0.20) = .732$

For Pass # 4, $\alpha = 60°$ $R_4 = (180/\pi)(.4178/60) - (0.33 \times 0.20) = .333$

For Pass # 6, $\alpha = 90°$ (final section) $R_6 = .200$

(c) *Calculating Roll Surface Geometry of Bottom Roll in Pass #2.*

For details, see Figure 5.163 to Figure 5.165. Figure 5.166 shows the final dimensioned roll drawing for the right half of the second pass bottom roll.

5.14 Computer-Aided Roll Design

One set of rolls may contain several hundreds or thousands of dimensions. The dimensions are interrelated within a roll, between the top and bottom rolls in a pass, and with all the other passes.

As technology improved, the trigonometrical calculations by using log tables have been advanced to mechanical and eventually to electronic calculators. The latest step in the development was to change to computers.

In addition to the speed, computer-aided roll design eliminates the tedious, monotonous calculations, drawings, recalculations, and redrawings. Each program and drawing can be saved and retrieved. Roll drawings can be replotted or modified at any time. The new software packages incorporate many convenient time-saving utility programs such as cost estimates, roll weight calculations, tool blank cutting lists, and so on.

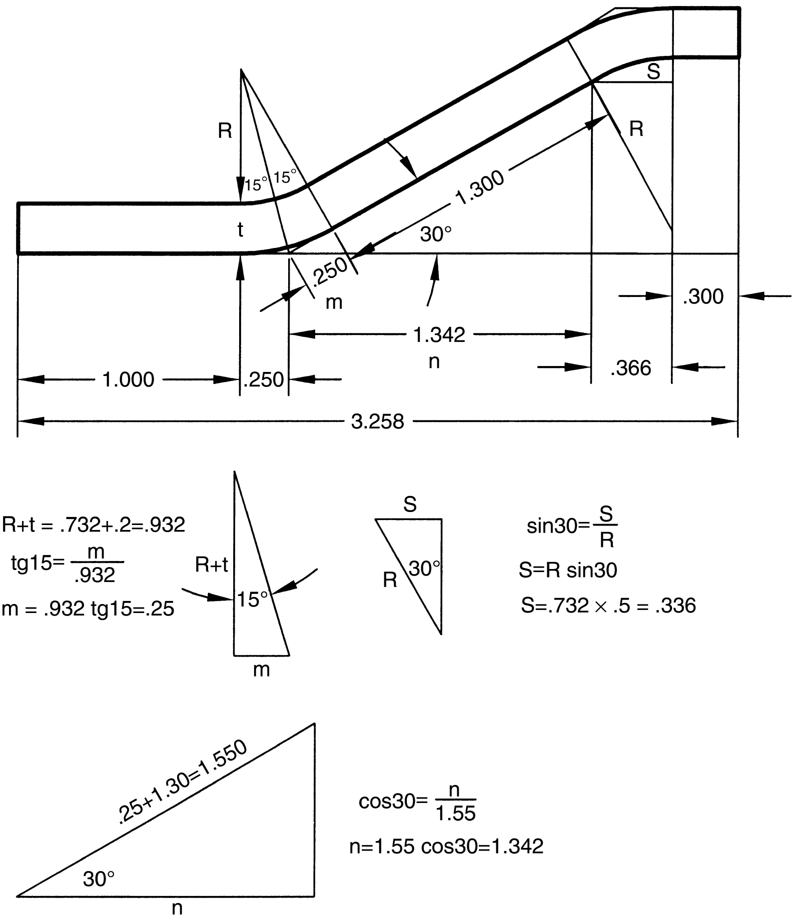
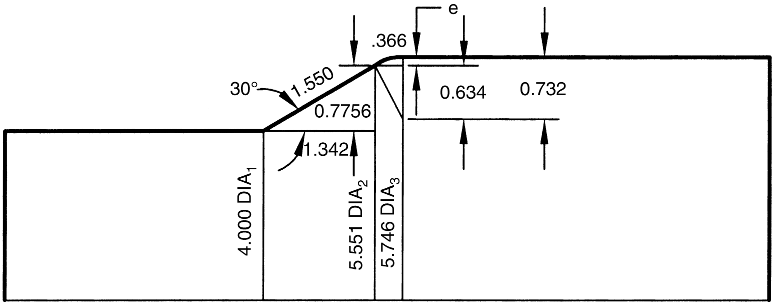


FIGURE 5.163 Manual calculation of cross-section.

The computer-aided roll design software packages vary in degree of sophistication, speed, and capability of providing all the design features used in the manual roll design. The improved software has opened the door to change roll design from art to science.

In most computer-aided roll design systems, the design starts with the input of the mill and other pertinent data (maximum material thickness, "*k*" factors, etc.). The next step is to generate the finished



$D_2 = D_1 + 2 \times .7756 = 4.000 + 1.551 = 5{,}551$

$D_3 = D_2 + 2 \times (.732 - .634) = 5{,}551 + .196 = 5.746$

FIGURE 5.164 Calculating the first elements of a roll.

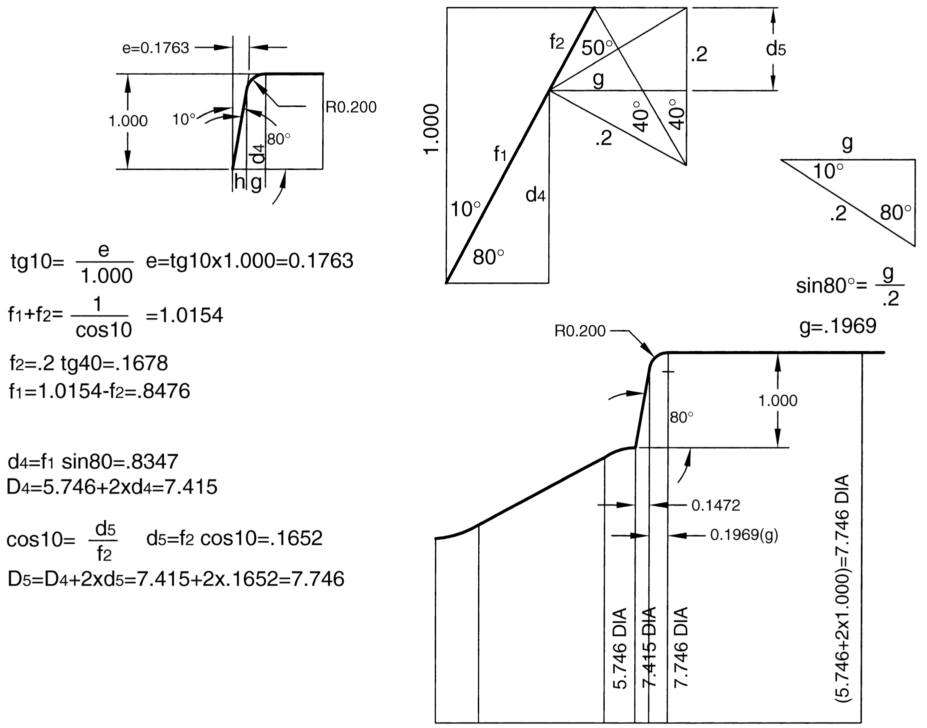


FIGURE 5.165 Calculating additional elements of the roll.

cross-section by entering the length of straight elements and the inside radius, angle, direction of bending of the curved elements, and the "*k*" factor. The blank size (strip width) is then automatically calculated. For roll design, the "plus" width tolerance should be added to the calculated strip width. After the flower is completed, the preliminary (raw) roll design commences by enveloping the section with the top and

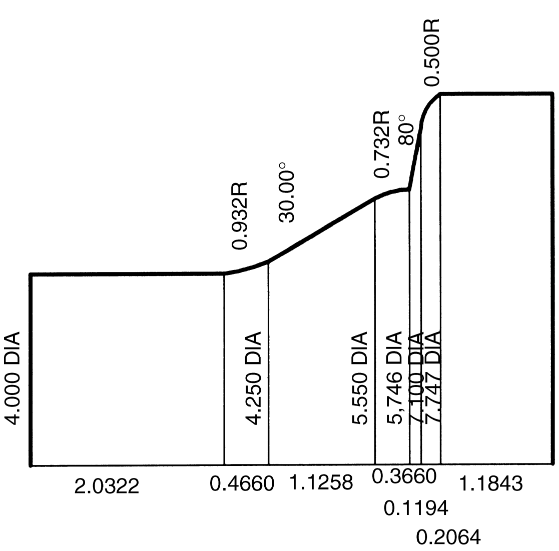


FIGURE 5.166 Fully dimensioned rolls.

bottom rolls at each pass, with lines commencing from the center line of the top and bottom shafts as shown in the left side of Figure 5.167.

This task is completed in seconds. The designer has to refine the raw rolls, taking into consideration several other factors such as how the leading edge of the strip will enter into the gap between the rolls, whether it is necessary to trap the edges to improve tolerances, how the rolls will be split, where to make cutouts, how to add radii to the roll edges, where to apply side-rolls, spacers, and so on. All of these decisions are based on the experience of the designer and are influenced by the factors described in the previous sections of this chapter.

Some programs provide only “raw” roll drawings and other features enveloping the product at each pass, working from shaft centers. To complete the roll designs, the output of these systems is further refined by one of the commercially available CAD systems. These relatively inexpensive computer-aided roll design software are used most frequently by the roll designers.

Other, more sophisticated systems complete the roll designs by adding all the features normally applied by manual design. They can trap, add lead-in flanges, radii, split spacers, and create setup drawings (Figure 5.168 and Figure 5.180). Other available software can calculate the bending allowance, recommend the required number of passes to form the section, prepare quotations, roll cutting lists and CNC programs for machining, and they may have additional features. Another software package calculates and graphically shows the anticipated stresses generated by the forming at each pass (Figure 5.169). All these computer-aided roll design systems, at different levels, have found widespread applications to save the designer’s time and provide better and more accurate roll drawings.

Further programs have been developed by researchers either developing their own programs or using the commercially available finite element modeling packages [73]. Many of the researchers conducted experiments with simple sections and, under given conditions, they are able to simulate surprisingly

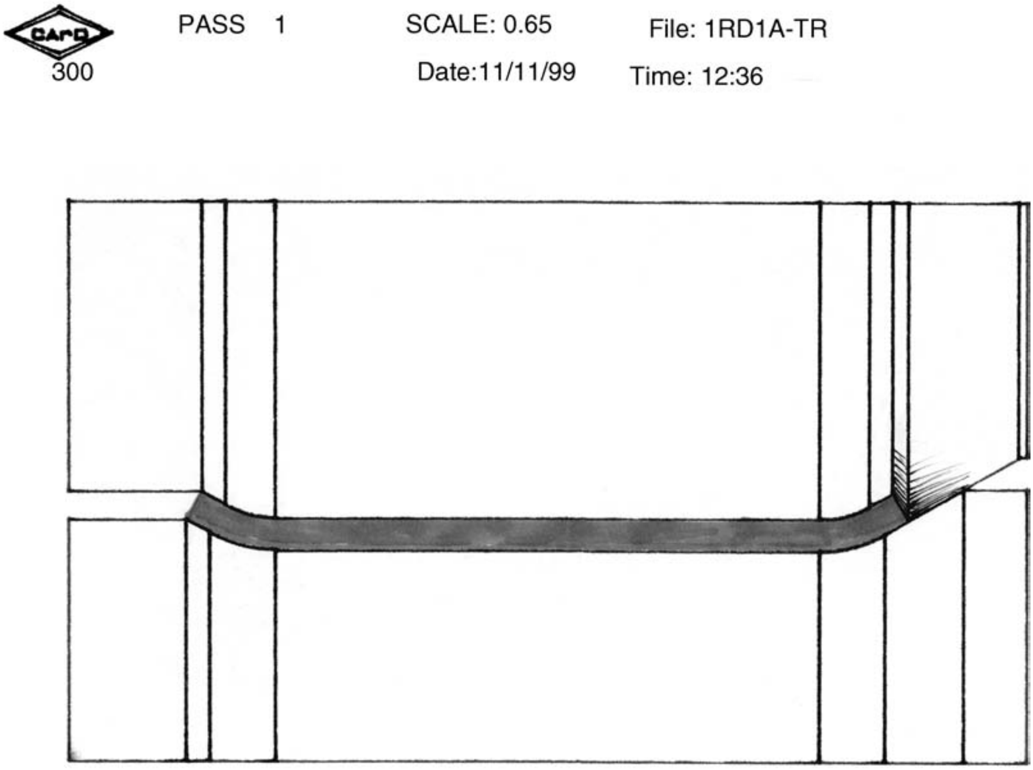
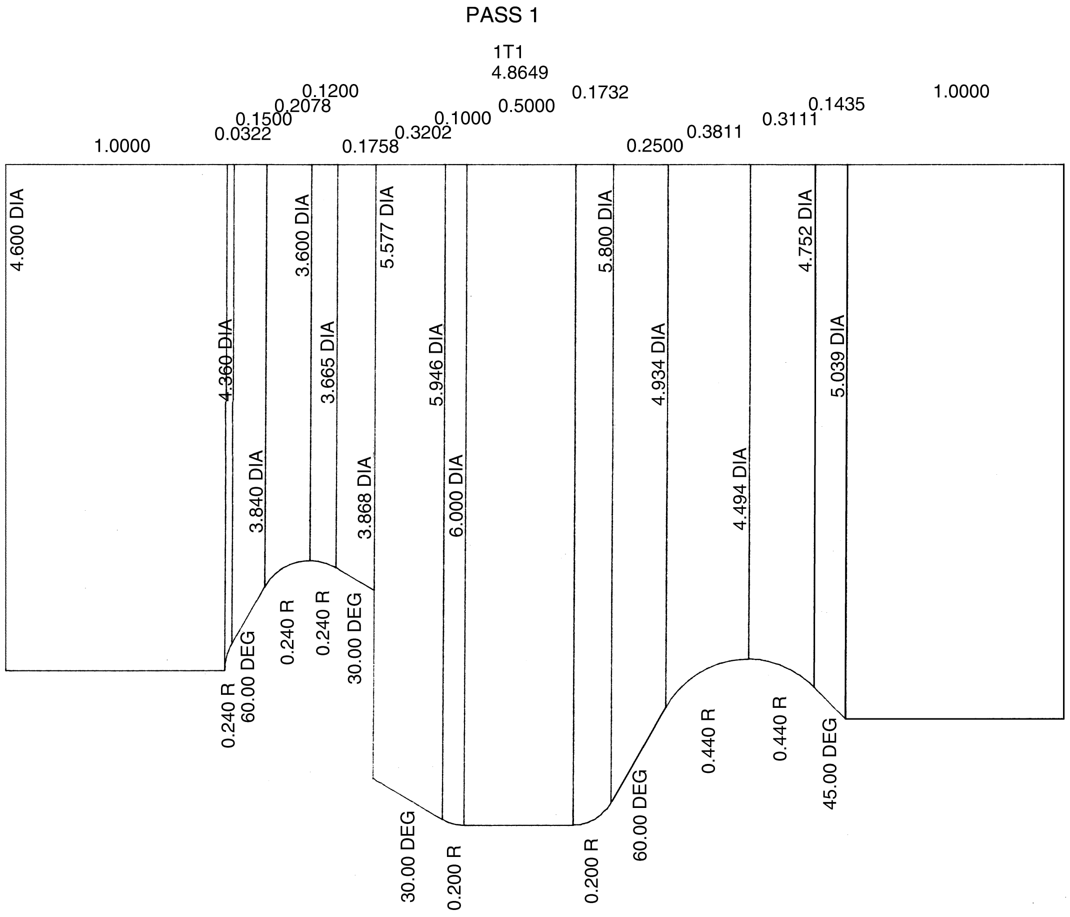


FIGURE 5.167 “Unedited” (raw) rolls, top and bottom rolls envelop the sections (left-hand side). Lead-in flange added on the right-hand side.



Cut a “marking groove at the
R.H. side of the rolls. Stamp
marking in each roll at
approx. 120 deg. to each other

Roll No. :

Material : D2

Job No. :

ROLL LENGTH : 4.865
RORE DIA : 2.501
TOL −0.0 +0.002
KEYWAY W/D : 3/8

COMPUTER AIDED roll DESIGN
CArD
DELTA ENGINEERING
ABC, INC
CUSTOMER
TOOL DRAWING
DESCR.
SCALE 2.00 | 17: 46 | 02-05-88
300 | EXAMPLE
ADV4-AD | JOB NO | SHEET | REV.

FIGURE 5.168 Some software can add trap, lead-in flanges, radius, and other features to complete the roll.

accurately a simple roll forming process. Most of these simulations require large computers and lengthy CPU time, which are not available to most roll designers, but some of the results have found their way into commercially available roll design systems.

However, regardless of the sophistication of the presently available programs, the know-how and expertise of the roll designers cannot be replaced. There is no doubt that further research in this field can yield additional data that will reduce the uncertainties which still exist in the roll design.

The following examples will show how a simple factor, such as the sequence of bending established by the designer, will influence the flow of material, the stresses developed in the strip and the provision for the operator to compensate for the nonuniformity of the material.

5.15 Examples

The first example shows some but not all of the bending sequence possibilities for a simple "C" channel illustrated in Figure 5.170.

Figure 5.170a	Lips at edges are formed completely in the first passes,
Figure 5.170b	Lip forming starts at the first pass, but it is completed in the sixth (last) pass,
Figure 5.170c	Same as Figure 5.170b, but the final lip bending is in Pass # 5,
Figure 5.170d	Legs are formed first, lips are formed in the last pass.
Figure 5.170e	All angles are bent in each pass.

In the case of more complicated shapes, the permutations in forming sequence and magnitude are limitless.

Even the forming of a simple "U" channel can be accomplished in different ways depending on the number of passes and the preference of the designer (Figure 5.171).

- Short legs formed from thin material may be accomplished in 2 passes (Figure 5.171a). For thick or high strength material, the first pass may require a very shallow bend to drive the material in. This is equally applicable to Figure 5.171b–e. Examples shown in these figures disregard the overbending requirements.
- Figure 5.171b shows the same section, but because of the condition, the leg is formed in 3 passes. Some designers may elect to have an even increase in all the process (b1) or have a smaller increase in the first and third passes, and a larger one in the second pass.
- If longer length or other conditions necessitate more passes, then again the designer may elect to have 4 equal increase in angles (22.5° per pass; see Figure 5.171c1) or 20° in the first and last pass, and 25° in the second and third passes (Figure 5.171c2), or even smaller first and last pass deformation (15 and 30° in the second and third passes).
- Some designers divide the horizontal axis to equal distances to establish the bending angles (Figure 5.171d). This figure shows the forming in five passes. The author does not recommend this approach.
- A well-proven approach is to add a small first pass forming angle, about 15°, depending on the thickness and mechanical properties of the material, to ensure a smooth, unaided entry of the strip end into the first pass. For thicker, high strength material, this angle may have to be reduced to 0°.
- The last pass may be only a 5° bend from 85 to 90° (Figure 5.171e). The remaining angles (in the example shown on this figure) 70° is divided by 4 (because there is a total of six passes in the example). The second and the one before the last bending will be reduced and the in-between angle increased to arrive to the total 90° (e.g., 10, 17, 20.5, 20.5, 17, and 5°). This approach provides the closest to a smooth slow-start slow-finish and faster in-between bending. The angles may be corrected by viewing the top view of the flow diagram to provide a smooth "S" shape.

There is an unusual, but very economical, way to form deeper channels from thin material. To minimize edge strain, the full depth is achieved in a long horizontal center distance between an entry pass and

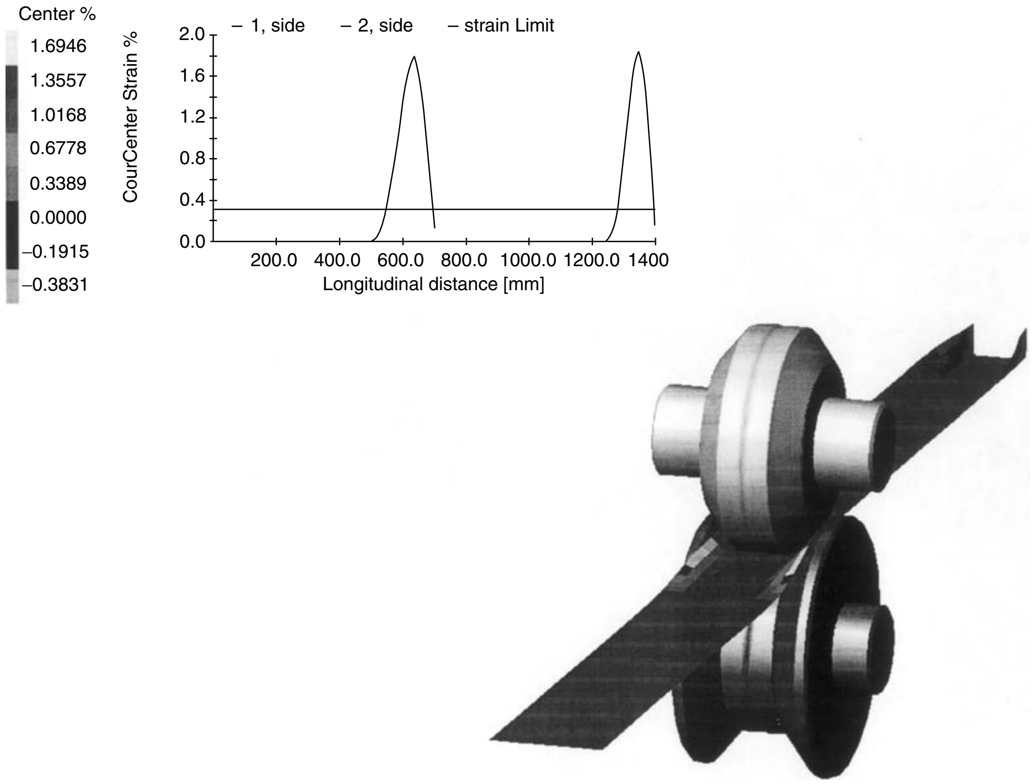


FIGURE 5.169 Forming stresses can be calculated and graphically represented by some software. (Courtesy of data M Software GmbH.)

the first pass. The entry pass (Figure 5.172) has a very shallow curvature to help to form the material (EP). At a sufficient distance, in the first pass of the mill, the section has a full depth "U" shape (1). The radius of the "U" should be large enough not to create permanent deformation in the material (approximately 40 to 60 times material thickness for mild steel). In the second pass (2), the bottom of the section is flattened with a radius in the opposite direction to compensate for springback. A sizeable section of the legs will also be straightened to the bend line, applying a shallow curvature opposite to the previous bending. The third pass (3) finalizes the section. Guiding the edges into the first pass is important to keep the length of the legs uniform.

The forming of ribbed panels depends upon whether the number of ribs is even or uneven. Figure 5.173a shows four ribs symmetrical to the center line. In this case, the center of the panel remains

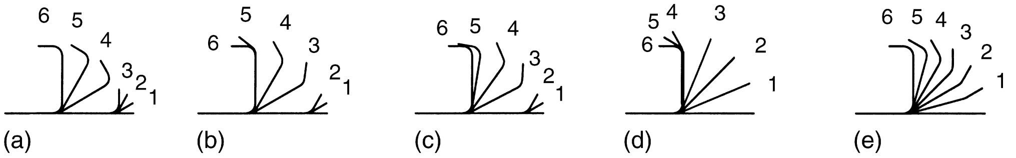


FIGURE 5.170 Different ways to form "C" channels.

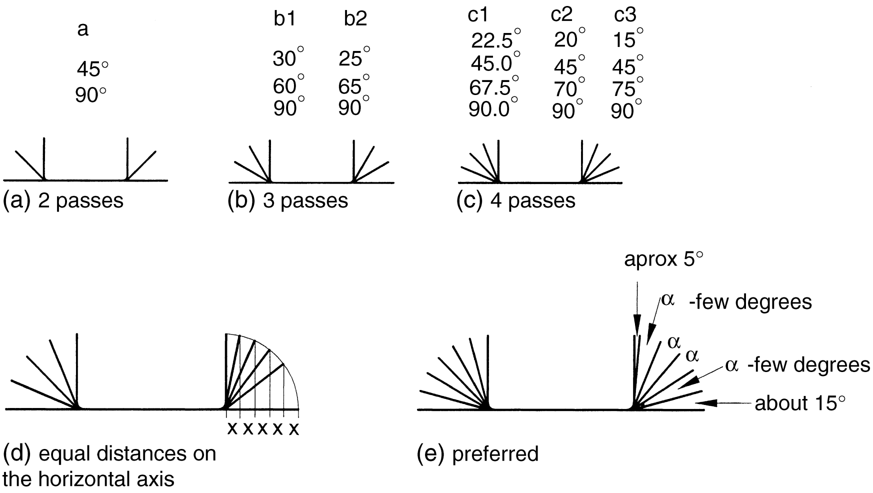


FIGURE 5.171 Depending on the conditions and the preference of the designer, even the forming of a simple U-channel can be approached in different ways.

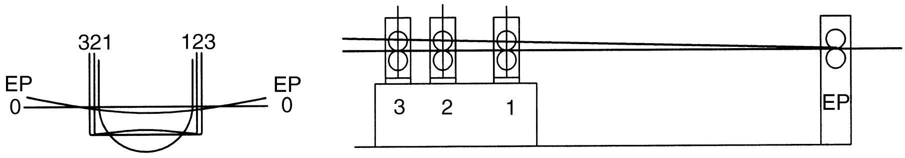


FIGURE 5.172 An unusual but very economical way to form deep "U" channel from thin material.

at the pass line level (neglecting in this example the possible slight increase in roll diameters). At first, the two cells left and right from the center line will be formed almost to the finished shape in, say, three passes. At the final forming fourth pass, the first two angles of the adjacent rib are also formed.

Figure 5.173b shows uneven number of ribs. The center rib is formed first and the center horizontal flat portion will ascend to the full height of the rib during forming. Similar to the previous example, the forming of the adjacent two ribs may start when the last forming of the center cell is completed and so on.

The next example shows an "N" shape cross-section with beads at the edges. Figure 5.174a shows the required cross-section, Figure 5.174b indicates a better orientation, which will induce less stresses. The forming may commence at the edges by completing the beads and then forming the rest of the section. During forming, the center part is rotated to almost vertical position. The same section may be formed by forming the legs and rotating the center part in the first passes and forming the edge beads in the last passes. The advantages of this forming method is that the formed beads (Figure 5.174c) will be stiffer than the unformed edges following method "d," and will thus create less residual stresses and deviation from straightness and flatness.

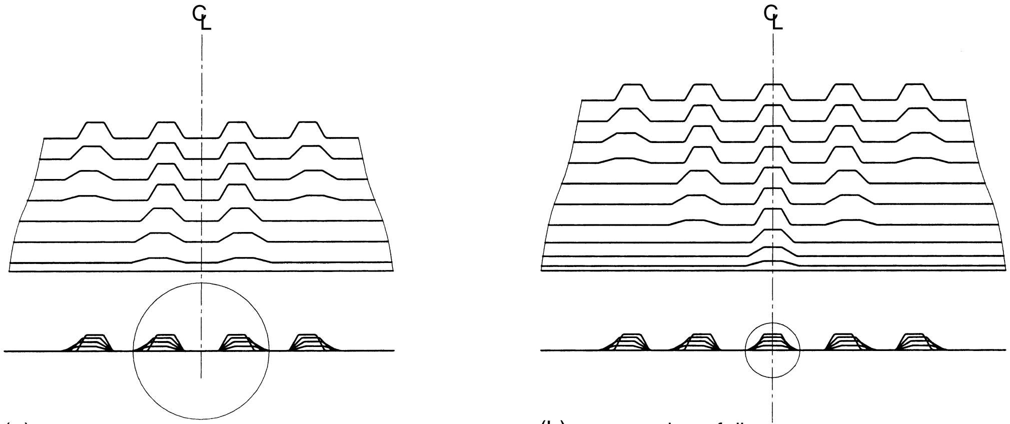
Figure 5.175 shows three different flower diagrams to form spring grids. Based on the roll designer's experience and the equipment, one of them will be used to design and make the rolls.

Figure 5.176 shows one pass to form the outside bottom corner of a section in different ways.

Figure 5.177 shows two flower diagrams, one forming the section with legs up, the other one with legs down. The increase of the roll diameters in the center section represents the pass-to-pass pass line diameter increase.

Additional examples of forming sections are shown in Figure 5.178a–c.

All of the above examples represent the "conventional" way of roll forming sections. However, the



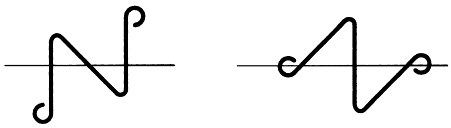
(a) even number of ribs (b) even number of ribs

FIGURE 5.173 Forming panels with even and uneven number of ribs.

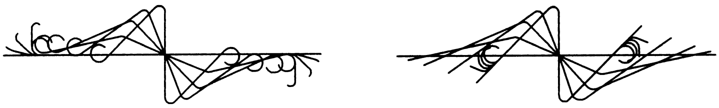
continuous pressure to manufacture better products at a lower price is forcing roll designers to seek improved forming methods. Several of these improved or radically new methods, such as variable pass line forming, tension roll forming, hot roll forming, incorporating thickness reduction into the roll forming process and others are described in Chapter 15. The application of these methods requires courage, new insight, sometimes different equipment, new approaches to forming sequences, new roll design software, and, most of all, new experience. However, the progress, forced by competition and the potential cost saving, will eventually convince the roll forming industry to change in new directions.

5.16 Roll Marking System

Most roll forming sets contain about 40 to 500 rolls and spacers. Each roll and each spacer must be installed at the right pass, on the specified top or bottom shaft, in the right sequence and direction. The roll forming industry developed a simple identification system, comprising of sets of combination of numbers and letters stamped into the rolls. The identification helps the operator or setup person to place the rolls at their correct position.



(a) Finished section (b) Better orientation



(c) Flower forming edge bend at first (d) Forming edge bend at the end

FIGURE 5.174 Forming a section in different ways to reduce stresses.

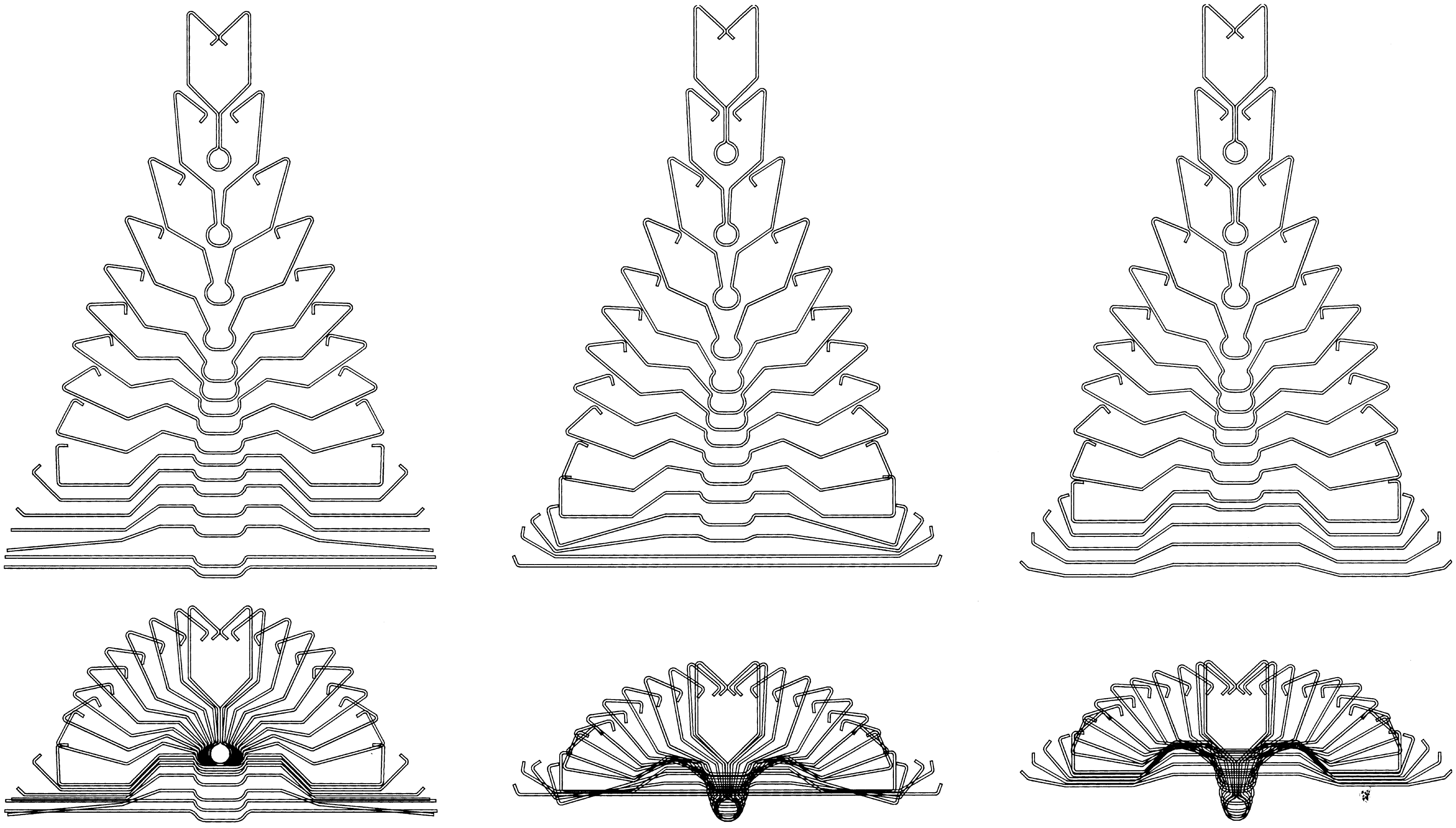


FIGURE 5.175 Three different ways to form “T” hanger bars. The diagram does not necessarily reflect the actual number of passes required for forming. (Courtesy of Worthington Armstrong Venture.)

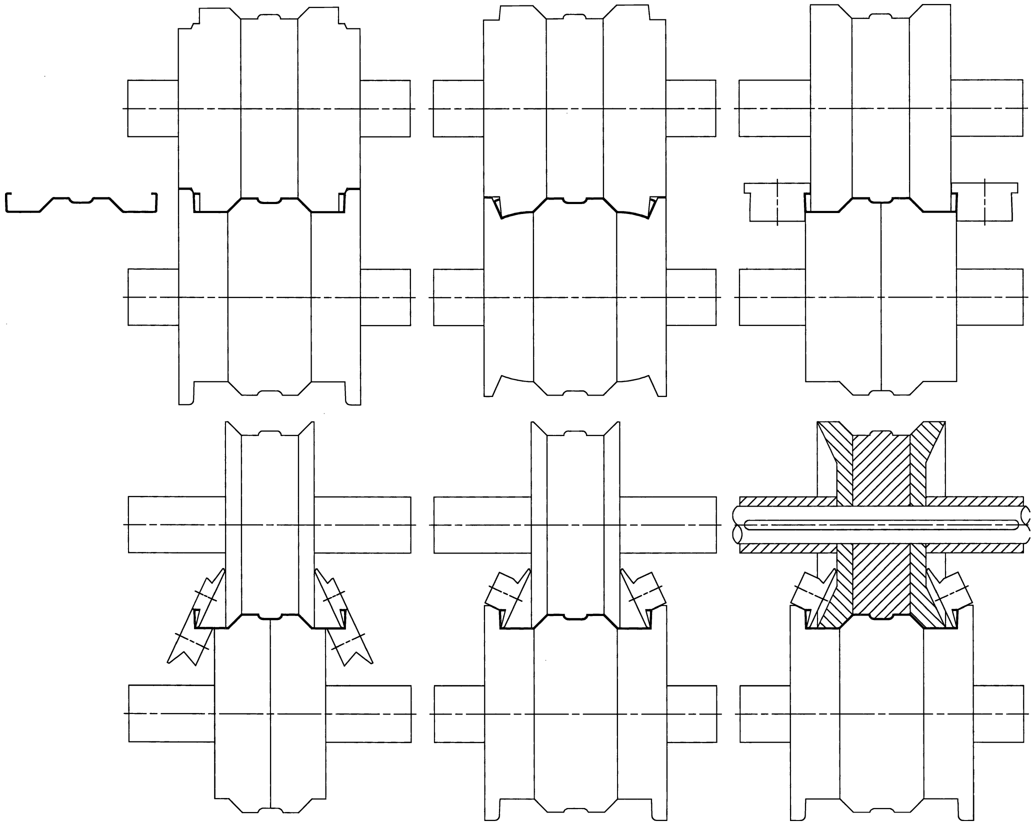


FIGURE 5.176 Different methods to form the outside 90° corners of a section.

The identification process starts at the roll design, when the number of passes is established. The strip enters into the first pass and exits from the last. The first identification number refers to the pass number.

Each pass usually has a top shaft and a bottom shaft. The second identification mark on the rolls is either "T" for the top or "B" for the bottom shaft location. Thus, all rolls and spacers mounted on the first pass top shaft are marked as 1T and on the bottom shaft 1B. Rolls on the second pass top shaft are marked 2T and on the bottom shaft 2B, and so on.

The next identification number in this group determines the sequence of the spacers and rolls on each shaft. On each shaft, the first roll (or spacer), which is installed and pushed against the side opposite to the operator, is marked as 1; the next roll (or spacer) is 2, the next if 3, and so on. For example, the first roll installed and pushed against the shaft shoulder on Pass 3 top shaft is called 3T1, the next two rolls or spacers on the same shaft are 3T2 and 3T3, and so on.

Side roll location marks are different. They also have a pass number but instead of T (top) and B (bottom) they usually are marked as "IN" or "OUT" ("IN" being the shaft shoulder/drive side of the mill, and "OUT" the operator side). If there are more rolls on a side roll stand, then the first one placed on the side roll shaft is identified as 1, the second one as 2 and so on. (For additional details, see Figure 10.14).

The roll and spacer identification numbers and letters are originated by the roll designer. Some designer using the above system for the rolls only, the spacers are given other designations (for spacer marking, see also Figure 5.78). Before the heat treatment of the rolls, the identifications are stamped into a groove on the side of the roll, which faces the operator after installation.

In addition to the location identification of the rolls described above, the rolls are stamped with two additional sets of numbers/letters groups. The second group of letter/number combination identifies the

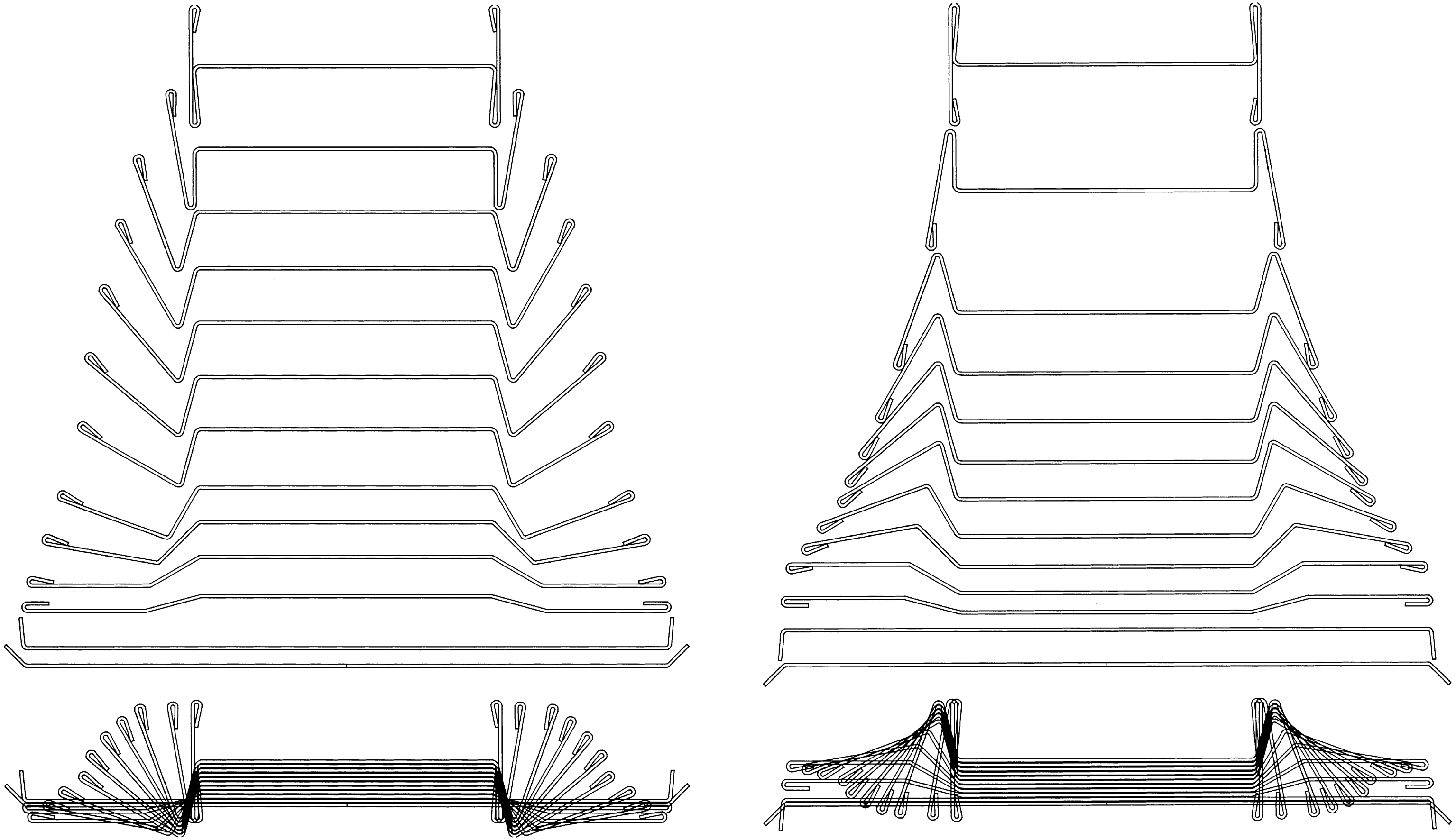


FIGURE 5.177 Forming the same section either up or down. (Courtesy of Engel Industries Inc.)

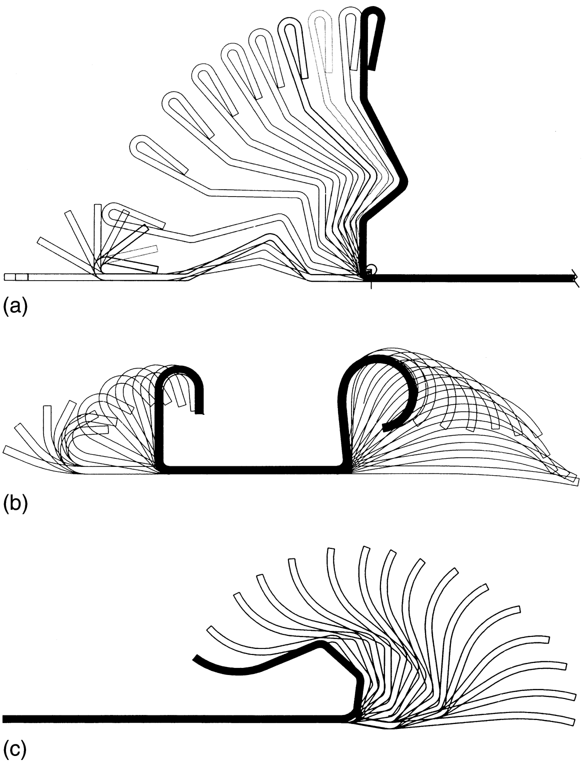


FIGURE 5.178 Flower diagrams of three sections. (Courtesy of Engel Industries Inc.)

job or product number and the supplier of the rolls. The third group specifies the roll material. The most frequently used roll identification system is shown in Figure 5.179. In the illustrated case the location of the roll is 22 B 3 (22nd pass, bottom shaft, third roll). The supplier and job numbers are DELTA STT 01 33 and the tool material is D2. The second and third groups of identifications are usually identical for all rolls in the set.

5.17 Roll Orientation

The roll can be installed in two different orientations by flipping them over 180°. For example, a tapered roll can be installed either with the larger diameter or with the smaller diameter facing the operator. To ensure the proper roll orientation, the roll marking should always be facing the operator.

Exceptions to the Rule. In roll sets where the rolls and spacers are placed in different locations on a shaft to accommodate width or other section changes, the location identification numbers will be mixed up (see Figure 10.13). Proper instruction (setup) sheets are required for each cross-section as well as for each pass.

5.18 Setup Charts

5.18.1 Rolls and Spacers

The instruction sheets specifying roll locations is known as "setup charts." Setup charts are prepared and used for every set of rolls, regardless whether the rolls have single or multiple locations. A setup chart is like a map. It describes the location of every roll, spacer and shim in the set. The charts are prepared by the roll supplier and are supposed to be provided with the roll set. These setup charts,

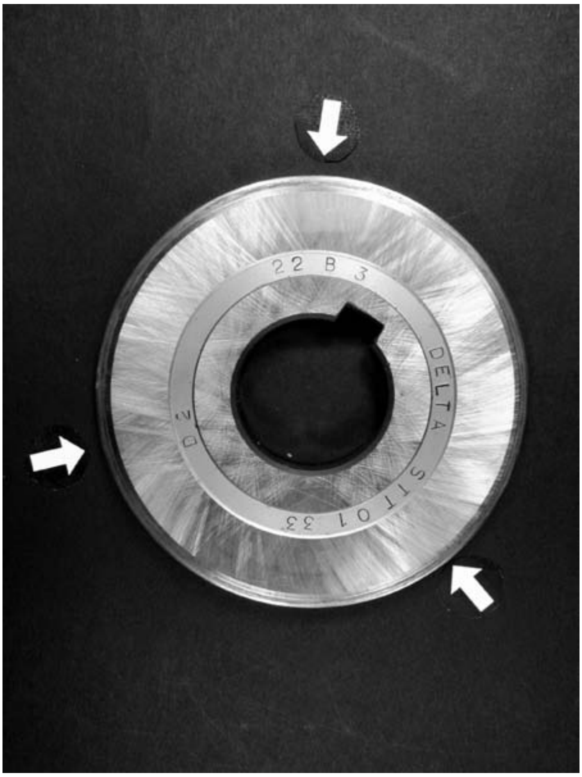


FIGURE 5.179 Typical roll identification markings.

often abbreviated to SU charts, are important and crucial instructions to set up the rolls and spacers correctly.

Plants using older or secondhand roll sets frequently struggle without setup charts. In these cases, the operators usually prepare their own setup charts to simplify and speed up the installation process. These charts are usually just a simple list of top and bottom shafts at each pass, followed by the roll and spacer identification numbers in the sequence as they are installed on the shafts. A few roll suppliers provide similar, oversimplified setup charts with the rolls. These charts can be helpful, but they are not sufficient to minimize setup times and errors.

Good-quality setup charts should show the following information of each roll and spacer (Figure 5.180) at every pass.

- Location
- Marking
- Length
- Contour

In this illustration, the spacers for Pass 12 are marked with the pass number, "T" for top or "B" for bottom shaft and "IN" for the drive side or "OUT" for the operator side locations. If shims are installed in the set, then the chart shows their locations and thickness too (note the 0.010-in. thick shim between Roll 12 B 1 and Roll 12 B 2).

Using this type of setup chart, a person can be trained in about half an hour to place the rolls and spacers into the right locations. However, the next step, in setting the roll gaps and making the final adjustments requires a knowledgeable operator with many years of experience.

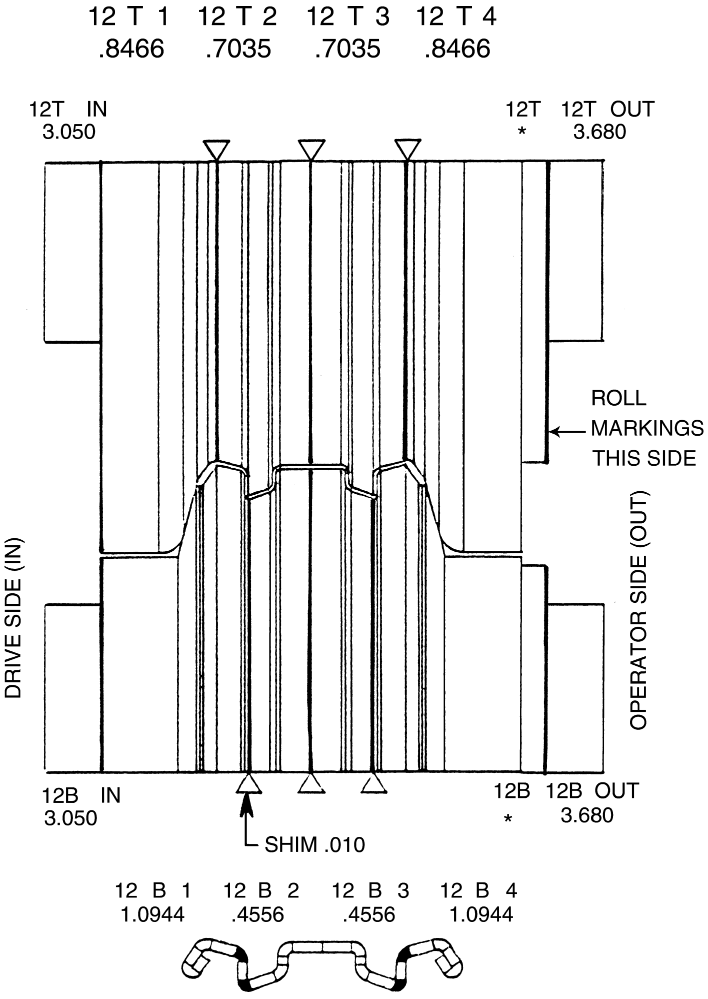


FIGURE 5.180 Proper setup chart.

The more advanced setup charts also indicate which bend-line is formed in each pass. The four darkened, bend lines shown at the bottom part of Figure 5.180 are bent at this pass. With this information, the operator can tell which pass needs adjustment to counteract the springback in a given bend line. Inexperienced operators often try to "squeeze" the last pass instead of making corrections at the pass, which forms the final bend in a specific bend-line.

It is true that an operator who frequently sets up a set of rolls may not require a setup chart. But what happens if this operator is away?

5.18.2 Shims

The thin shims used in many sets are not marked (see also Section 5.7.5). To ensure that during setup the right shim is placed at the right location, their positions are indicated on the setup chart. The most common way of identification of their position is to write "SHIM" followed with the thickness and an arrow pointing to its location as shown on Figure 5.180.

5.18.3 Bending Charts

The bending chart (Figure 5.181) reveals the bend line that is formed at each pass (marked solid black). Although the bending chart is seldom used, looking at it is the easiest way to find the pass that made the final bending of any bending line. This allows the operator to adjust the correct pass, instead of making the common mistake of "squeezing" the last pass to correct all mistakes.

5.18.4 Good Setup Chart Set

How to prepare a good setup chart?

- Rule number one: the setup chart should be operator-friendly.
- Each set of rolls should have a separate setup chart.
- If a set of rolls is used to roll different profiles by changing the location of the rolls, spacers or shims, then each shape should have a separate set of setup charts.
- Each set of setup charts should have one or more covering pages. The cover page(s) should show the following information:
  - ◦ Company name
  - ◦ Product name/number

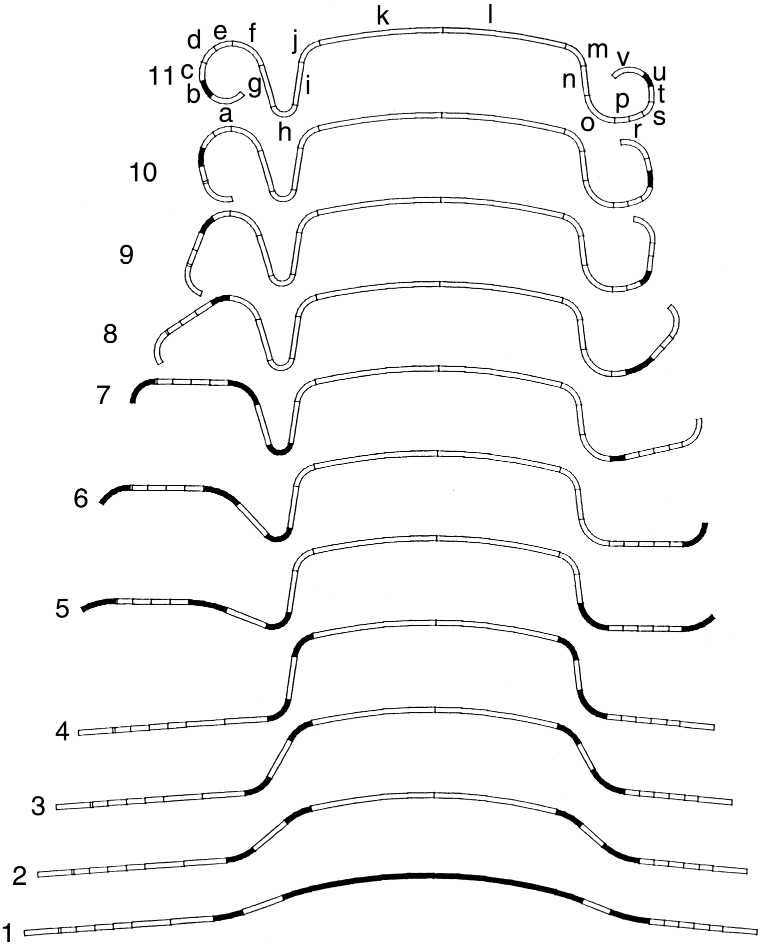


FIGURE 5.181 Sequence of bending chart. (Courtesy of AMTRI.)

  - Product drawing number, revision number and issue date
  - Information about prepunching, prenotching, pre- or postcutting and possible secondary operations in the mill
  - Reference to cutoff or other operations
  - Other information that are stamped on the rolls (e.g., work order number)
  - Identification of the mill onto which the rolls are installed. The mill details should include shaft diameters, top-bottom shaft rpm ratio or indication of free running shafts, number of passes, roll space, horizontal distance, max–min vertical shaft distance, availability of lubrication, and so on.
  - Material specifications for the product (including the actual maximum and minimum thicknesses, surface conditions, special surface requirements)
  - Roll material and surface hardness
  - Roll supplier name, reference to roll drawing numbers, revision numbers and dates
  - Locations, specifications, and setup instructions of the side rolls
  - Availability of "go–no go" gages or other measuring devices specifically used for the described profile
  - All information important to set up and use the rolls correctly
- Bending chart (can be a great help to the operator).
- Letter size paper should be used for setup chart. Those designers who issue a chart showing several passes on a huge drafting paper usually have never tried to set up rolls using a chart.
- Operators often work in areas that do not have the same good lighting conditions as available in the drafting office. Therefore, lines should be clearly visible under adverse lighting conditions; all letters, numbers, symbols should be easily readable.
- Each page of the chart should be placed in individual plastic protective cover to minimize smudging and oil marks.
- The cover page(s) and the setup sheets should be issued to the operator in a ring binder to keep the set together and to facilitate the change of individual revised page(s).

5.18.5 Updating the Setup Chart

A good setup chart should always be delivered with all sets of new rolls. To reflect any modifications made to the original charts during the setup test, the roll supplier should update the setup charts before delivering them to the customer.

After using the rolls for a long time, the shims or shim locations may have to be changed due to bearing wear or replacement, roll wear, change in material quality or thickness, or for other reasons. It is very important that any alteration to the setup should be recorded on the charts. It is recommended the master sets of all setup charts be kept in one place, for example, at the plant engineering office. Changes in the setup should be reported immediately to the person responsible for the chart updates who will then enter all the changes into the masters and will issue an updated setup chart with a new revision number(s) and date to the operator. This system eliminates the common problem at many companies whereby various people may possess two or three different setup charts and, often, none of those charts is correct. Using incorrect setup charts, leading to incorrect roll setup, is a frequent cause of wasted setup times, inferior quality products, and increased quantity of scrap.

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6.1 Design Considerations

Owing to the high efficiency of roll forming lines, material may represent 65 to 95% of the manufacturing cost.

To manufacture the right product at the right price, it is important to select the right material.

The designer or the person who selects and specifies the material must take a number of factors into consideration, such as:

1. Mechanical properties
2. Manufacturability (formability)
3. Appearance
4. Price
5. Availability of material
6. Equipment and tool capacity
7. Weight of product
8. Customer's specification
9. Supplier's or other specifications
10. Corrosion resistance (application, environment, storage, discoloration, cathodic resistance)
11. Heat and wear resistance
12. Weldability, acceptance of coatings
13. Susceptibility of surface (scratch, mar)
14. Market acceptance
15. Electrical, magnetic, or other properties

Only the relevant requirements are considered when material is selected. However, missing just one of the above factors may result in technical, marketing or financial problems.

6.2 Mechanical Properties

Safely withstanding the expected maximum load without permanent deformation (or to stay within the specified deflection) is a basic requirement for any product. The "resistance" against the load is a function of the cross-section and the mechanical properties (or in loose terms the "strength") of the material.

The most important mechanical properties are the yield strength, tensile strength, and elongation.

6.2.1 Elastic and Plastic Deformation

A straight piece of steel wire or strip, rigidly held at one end, bent by a small load to a few degrees, will "spring back" to its original shape when the load is released. By placing a double load at the end of the steel specimen, the rate of deflection will be twice as high but the specimen will still return to its original shape when the load is taken off. In other words, the specimen is loaded within its "elastic" range (Figure 6.1).

After increasing the load and the deflection to a certain limit, the specimen will not return to its original shape upon the removal of the load. At that load, the wire will remain "permanently" deformed because the stresses in the material exceeded the yield strength limit.

Similar occurrences can be observed with springs (Figure 6.1). The linear relation between load and deflection is utilized in the fish scale but the load is always kept safely within the elastic range of the spring. If a spring is stretched over its elastic range (over yield limit), then it will not spring back to its original shape.

6.2.2 Testing Material, Yield and Ultimate Strengths, Elongation

Materials are tested for their mechanical properties by applying tension (pulling force) on the test specimens. The test (tensile) specimens are cut and machined out from the material to be tested. After measuring their cross-section and marking a specified length, the specimens are placed between the jaws of a testing machine (Figure 6.2). The gradually increasing load and the elongation are accurately checked.

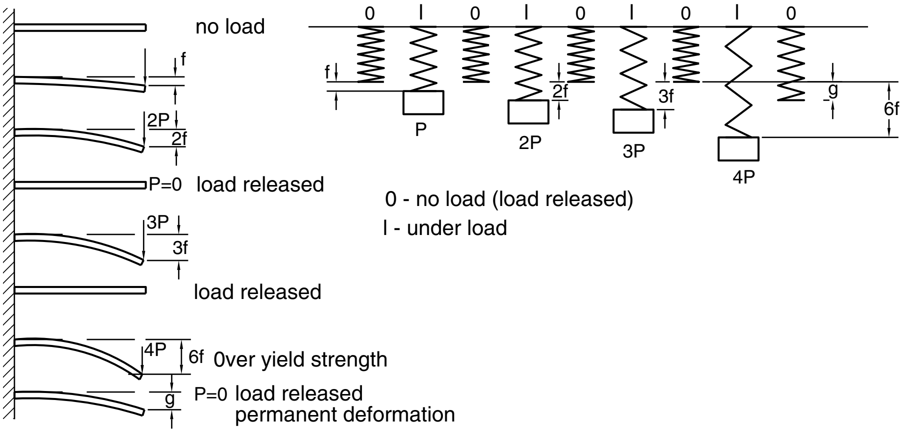


FIGURE 6.1 Loading and unloading a beam and a spring.

Under any load (stress), the test specimen will elongate (strain). Doubling the load (stress) will double the elongation (strain) — up to a certain load. If the load is released before the specimen starts to yield, then the specimen will return ("shrink back") to its original length (Figure 6.3). At a specific stress, the strain will increase without increasing the stress. In other words, the material will "yield" under the load. If the load is released after yielding, then the specimen will not regain its original length but will remain "permanently" longer. Where this yielding of material occurs, the stress is called the "yield stress."

To eliminate the influence of the specimen size on the load, for stress calculations the test load is divided by the area of the original specimen's cross-section. The load (lb or N) divided by the area (sq. in. or mm^2) is the "stress." For example, a 2000 lb load on a test specimen having a cross-section of

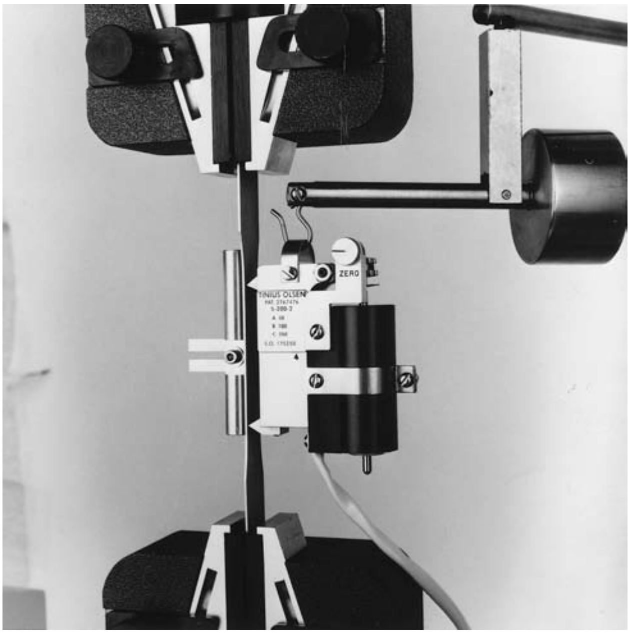


FIGURE 6.2 Testing tensile strength. (Courtesy Tinius Olsen T.M. Co.)

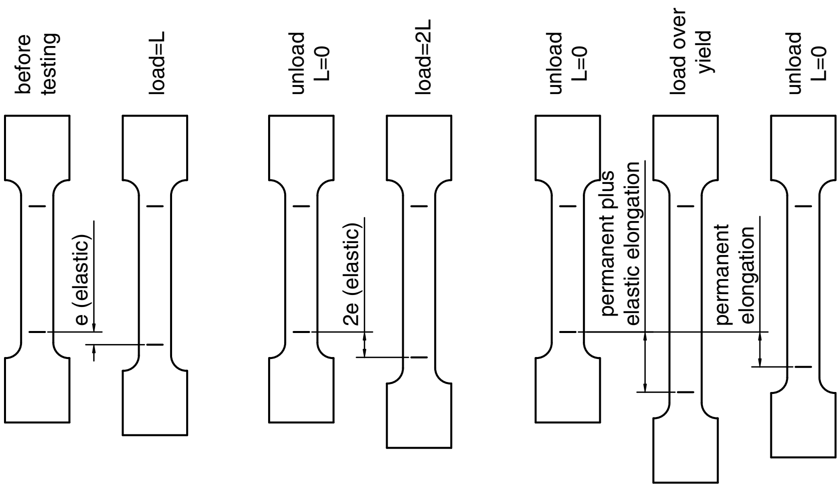


FIGURE 6.3 Test specimen loaded below yield will regain its original length when unloaded, but loaded over the yield limit will cause permanent deformation.

0.1 in.^{2} will create a 20,000 psi stress ($2000 \div 0.1 = 20{,}000$). In many cases, the yield limit is clearly recognizable on stress–strain graphs made by plotting the loads (stress) and the corresponding elongations (strain; Figure 6.4 and Figure 6.5).

After a certain amount of “yield,” to further increase the elongation, the load has to be increased. Under the gradually increased stress, the specimen elongates further, and at the same time, its cross-section reduces evenly. At one point, however, the test specimen starts to reduce its cross-section visibly at one localized area. In technical terms, it will start to “neck.” Because of the reduced cross-section at the necking, elongation will further increase even at a reduced load. Finally, the specimen will break. The maximum load divided by the original cross-section gives the maximum or ultimate “tensile strength” of the material.

If the load is released at any point during the test, then “permanent elongation” (strain) of the unloaded specimen can be measured. The permanent elongation will be equal to the elongation under load “minus” the elastic elongation (Figure 6.4). After loading the specimen again, the stress–strain graph will continue its original path.

Comparing the stress–strain diagrams of different materials (Figure 6.5), it became obvious that the low strength, high elongation material (Material #1 in this Figure) will have a different diagram than a higher strength, less ductile material (Material #2). An even higher strength and lower elongation material will again provide a different stress–strain graph (Material #3).

Figure 6.5 also shows that, assuming both are steels, Material #2 and Material #3 have the same “slope” up to the yield point. This means that the elongation created by a given load is the same for both the low strength and high strength steel. Of course, the high strength material will accept a larger load than the low strength material before it yields and permanently deforms. The slope representing the ratio between strain and stress expresses the elastic modulus (E), and is almost identical for all steels, approximately 30×10^6 psi (2056 GPa). Therefore, a mild steel wire and a spring steel wire, with the same cross-section, will deflect the same amount under the same load, regardless of their yield or tensile strength. However, higher strength steels can carry higher loads and will remain elastic under loads, which would permanently deform lower strength steels.

Assume that Material #1 in Figure 6.5 is aluminum and has a different stress–strain slope from steel. The different angle of the slope means that the elastic modulus of aluminum is different from steel. Actually, the elastic modulus of aluminum is about 1/3 of that of steel (Table 6.1). Therefore, under the same load, aluminum specimens (regardless of their type) will deflect about three times as much as steel specimens of the same cross-section.

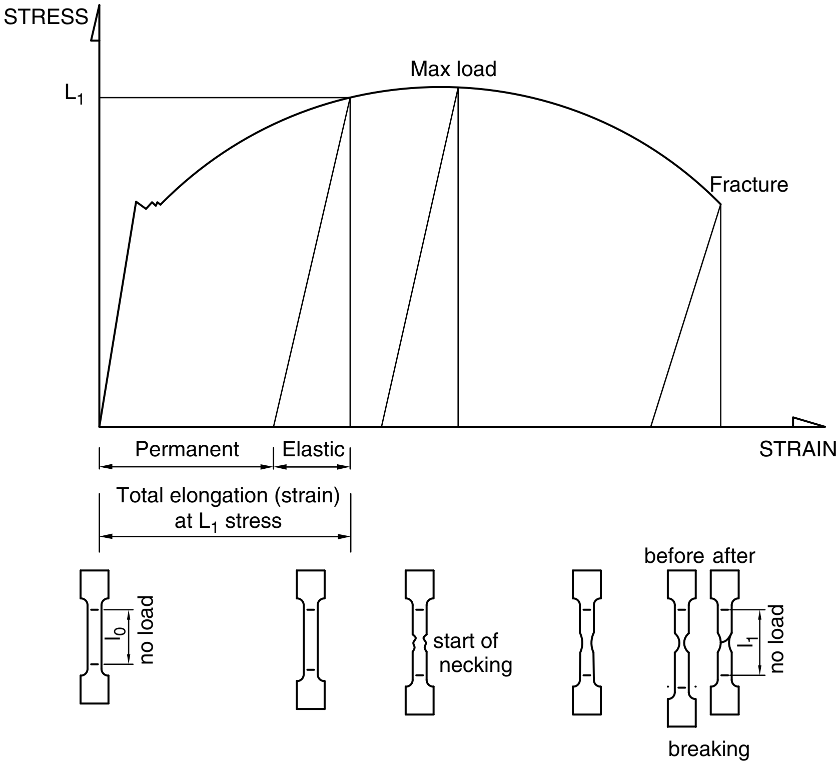


FIGURE 6.4 The shape of test specimen at different stress/strain points during testing.

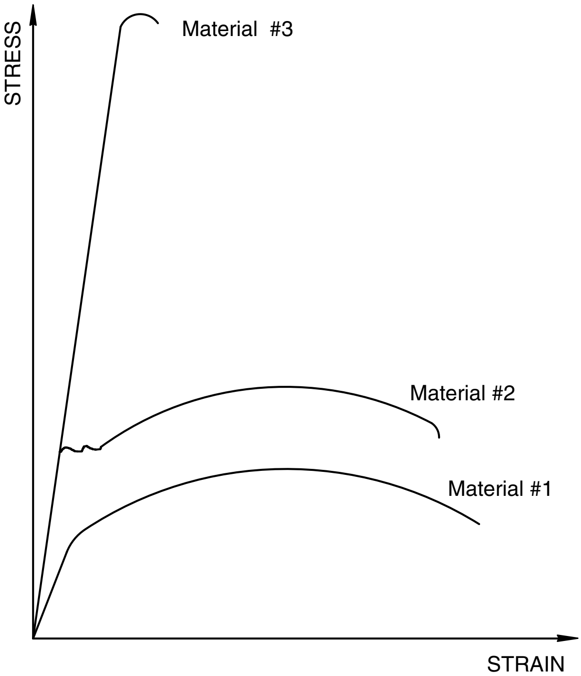


FIGURE 6.5 Stress–strain diagram of different metals.

Not all types of materials display a definite "yield" point. It is generally accepted that for these materials, the stress, which creates 0.2% elongation, will be the yield stress (Figure 6.6).

Total elongation (*e*) is the ratio of the increase in length divided by the original specimen length (Figure 6.7). The elongation is normally expressed in percentage.

North American standards specify that elongation should be measured in 2 or 8 in. lengths. The measured permanent elongation includes the increased elongation at the "neck"; therefore, the 2-in. long specimens of the same material display a relatively larger elongation than the 8-in. long.

TABLE 6.1 Elastic Modulus Guideline

Metal	Alloy	GPa	10^3 psi
Steel	Low carbon and high strength	202 to 205	29.5 to 30
Maraging Steel	18 Ni	186	27
Stainless Steel	302, 316	190	28
Aluminum	1100	69	10
Aluminum	2024	72	10.6
Aluminum	3003	70	10
Aluminum	6061	68	10
Copper		115	17

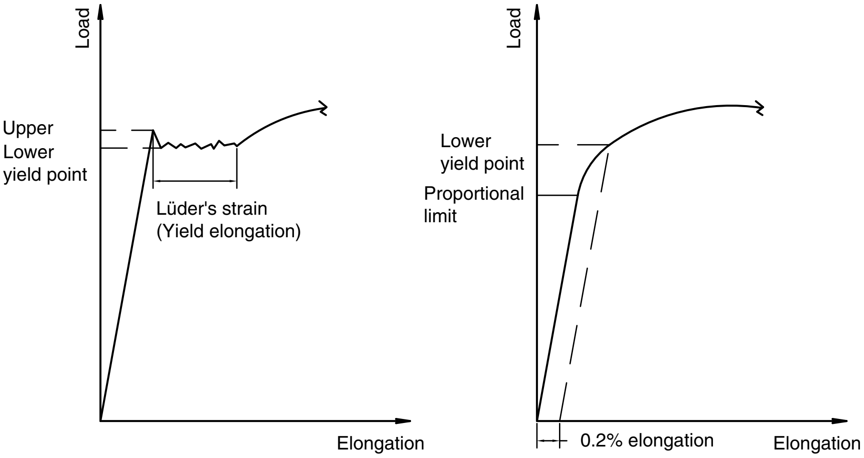


FIGURE 6.6 Stress–strain diagrams showing discontinuous and continuous yield points.

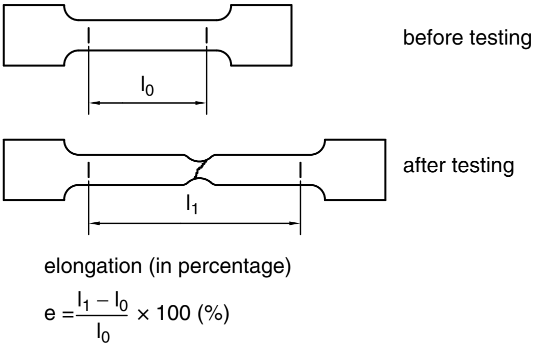

before testing
l_0
after testing
l_1
elongation (in percentage)
$e = \frac{l_1 - l_0}{l_0} \times 100$ (%)

FIGURE 6.7 Elongation is calculated from the permanent deformation of the test specimen (after fracturing).

6.3 Crystalline Structure of Metals

Metals have crystalline structure. Most crystals are so small that they can only be observed under microscope. Crystals have different mechanical, electrical, and other properties depending on the direction of their axis.

Impurities, alloying elements, and rate of cooling are some of the reasons why the crystals of the commonly used metals are not "perfect." Perfect crystals have extremely high strength, but imperfections can create "slip planes" along dislocations in the regular rows of atoms. These dislocations usually move along a plane, within a crystal to its boundaries or to other obstacles and then they stop. By "using up" these dislocations during plastic deformation, the material "work hardens." After a certain amount of deformation, there will be no more dislocation planes left and the metal loses its plasticity. Metals can also be hardened by blocking the slip planes with impurities, with alloying elements, by creating small crystals or by heat treatment.

Dislocations are not visible on roll formed products, but they may create visible marks during deep drawing (Lüders lines).

6.4 Forming Metals

In well-designed products where a "safety factor" was used in the calculations, the actual stresses will never reach the yield stress. Therefore, products shall not permanently deform under the maximum load. Only accidental overloads such as crashing a car or overloading a structure will create permanent deformation.

Forming any metals, however, must be achieved with stresses above the yield stress. Material formed with a stress below yield would spring back to its original shape. The forming stress should not exceed the maximum tensile stress, otherwise the product will crack or tear during forming.

A quick glance at the stress–strain diagrams (Figure 6.8) reveals that the larger the difference between the yield and the ultimate tensile stresses, and the larger the elongation, the better the chance is to form the metal. It is more difficult (even impossible) to form metals with extremely high yield and tensile stresses and having a near zero elongation. These materials will crack at the sharp bend lines because the elongation in the outside fibers, created by the bending, would be larger than the maximum elongation of that material.

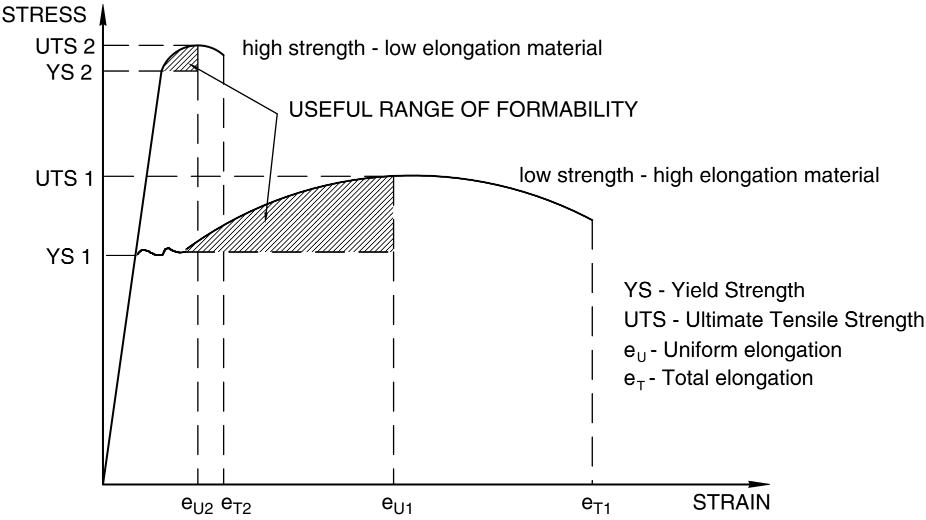


FIGURE 6.8 Assessing formability from stress–strain diagram.

During bending of the metal, the outside surface will stretch and the inside will compress. Theoretically, at the center of the bent specimen is a "neutral axis," which will remain at its original length (Figure 6.9a,b). In practice, for a variety of reasons, the inside will compress less and the outside will stretch more. As a result, the bent section (corner) will be thinner and the "neutral axis" will shift closer to the inside surface (Figure 6.9c,d).

Let us assume a practical case where the inside radius is equal to the material thickness ($r = t$) and the neutral axis is at 1/3 thickness away from the inside radius (instead of the theoretical 1/2 material thickness). In other words, the bending factor "k" is 0.33 instead of the theoretical 0.50. The theoretical elongation (strain) of the outside fiber in ratio to the neutral axis (which does not change length) can be calculated as follows:

Length of the outside fiber $L_0 = (r + t)\alpha$ and the "k" factor is 0.33.
Length of the neutral axis $L_n = (r + 0.33\ t)\alpha$

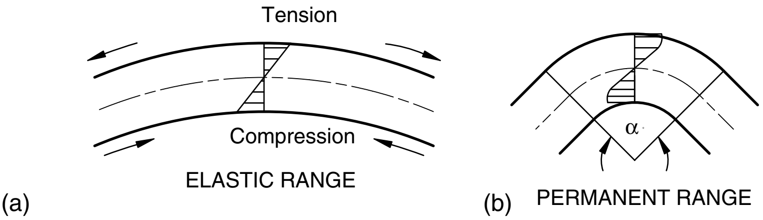
where:

$r =$ is the inside bend radius
$t =$ thickness of the material
$\Theta =$ angle of bending radians
$L_0 =$ length of the bent outside fiber
$L_\mathrm{n} =$ length of the bent neutral axis
$e_0 =$ elongation of the outside fiber
$k =$ is the bending factor.

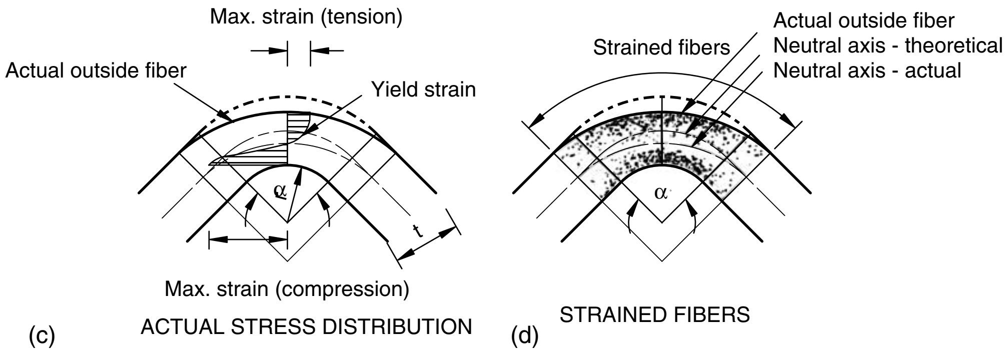
The theoretical strain (elongation) in percentage will be

$$e\,(\text{in.}\%) = \frac{L_0 - L_n}{L_n} \times 100 = \frac{(r + t)\alpha - (r + 0.33\ t)\alpha}{r + 0.33\ t\alpha} \times 100 = \frac{r + t - r - 0.33\ t}{r + 0.33\ t} \times 100$$

$$= \frac{t - kt}{r + kt} \times 100 \tag{6.1}$$



(a) ELASTIC RANGE (b) PERMANENT RANGE



(c) ACTUAL STRESS DISTRIBUTION (d) STRAINED FIBERS

FIGURE 6.9 Stress–strain distribution at formed bend line.

and

if $r = t$ and $k = 0.33$, then $e_0 = 50\%$
if $r = 4\ t$ and $k = 0.38$, then $e_0 = 14\%$

The actual elongation will be less, because during bending the material gets thinner at the corners. Therefore, the outside fibers stretch less. Furthermore, the elongation is not restricted to the exact corner only; material under tension "pulls in" material from the adjacent areas. Therefore, the outside fibers actually strain (elongate) considerably less than the calculated one shown above.

Notwithstanding the above effect, the strain can still be high at the corners when a sheet is formed to a too sharp radius (small inside radius). In the case of a sharp radius, material with limited elongation can crack or break.

Some material can be formed with a zero inside radius (folded back on itself) without outside cracks. Other material may require inside radius equals to one, two, or more times the metal thickness. For instance, 80,000 to 100,000 psi (550 to 690 MPa) yield strength steel with approximately 2% elongation may require a minimum inside radius equal to or larger than four times the material thickness or $r = 4\ t$. Most higher strength materials, even up to 220,000 psi (1500 MPa), can be formed with four times metal thickness inside radius (Table 6.2).

The cracking or breaking at the outside layers is also influenced by other factors. It is well known that during shearing, only a part of the material is sheared through "cleanly," the rest of it breaks away. The burr at the edge contains microbreaks, which are crack initiation sites. Moreover, the entire edge is work hardened and has lower formability than the parent material. Brake forming of thicker metals with such a rough sheared edge can create edge cracking (Figure 6.10). Bending with the burr on the compression side of the bend can potentially reduce the incidence of edge cracking. The crack may propagate only 0.5 to 1.5 in. from the edge of the sheet. Cutting products to length after roll forming does not create this problem.

Cracking is also affected by the microstructure of the material. Large, rough inclusions and certain alloying elements contribute to cracking. With proper alloying and treatments (inclusion shape control), the inclusions can be controlled and the minimum bending radius of some high strength steels have been reduced by 50% or more.

Standards or supplier's tables provide data for the recommended minimum bending radius (some standards refer to minimum bending diameter). In most cases, the metal strip can be roll formed with the same or even smaller bending radius than it can be brake formed.

TABLE 6.2 Influence of Mechanical Properties on Minimum $r : t$ Bending Ratio (90° Bend)

Yield Strength	Minimum Bend Radius
Low Carbon and IF Steel, Grades 2 to 5	$r = 0$
Grade 1 and others up to 40,000 psi (275 MPa) Yield	$r = 1\ t$
40,000 to 60,000 psi (275 to 415 MPa) Yield HSLA	$r = 2\ t$
70,000 to 80,000 psi (480 to 550 MPa) Yield HSLA	$r = 3\ t$
80,000 to 100,000 psi (550 to 690 MPa) Yield Cold Worked, 1 to 3% elongation	$r = 4\ t$
180,000 to 200,000 psi (1240 to 1380 MPa) Yield UHS Martensite	$r = 4\ t$
Stainless Steel Annealed 301, 302, 304, 305, 309, 310, 316	$r = 0.5\ t$
Stainless Steel one-quarter hard 301, 302, 316	$r = t$
Stainless Steel half hard 301	$r = 2\ t$
Stainless Steel Annealed 405, 410, 430, 442	$r = t$
Aluminum 1100, 2014, 3003, 3004, 5005, 6061 (All "0" Temper)	$r = 0$
Aluminum 1100, 3003, 5005 (All "H12" Temper)	$r = 0$
Aluminum $t < 0.060$ (1.5 mm) 3003, 3004, 5005 (All "H18" or "H38")	$r = 1\ t$

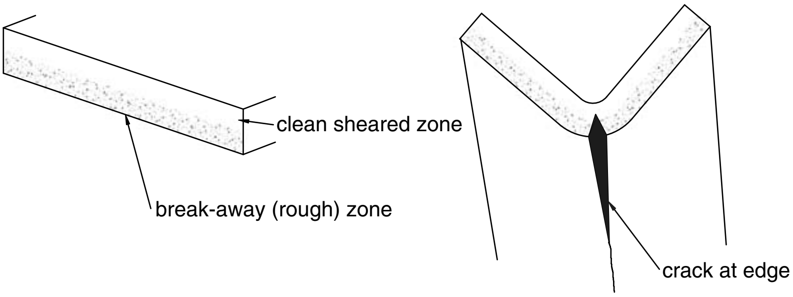


FIGURE 6.10 Rough, sheared edge may contribute to cracks at edges.

6.5 Increasing the Strength of Metals by Cold Working

The yield and tensile strength of metals can usually be increased by cold working, alloying, heat-treating and combinations thereof. For example, bending a piece of wire several times back and forth at the same place will harden and eventually break the wire. The reason for the breakage is the repeated bending, which is cold working. With each bend, the wire gets harder, its elongation is reduced, to the point where it cannot take any more cold work and it breaks.

The same phenomenon occurs when metals are rolled. To achieve the specified material thickness, the metal strip is passed through a set of rolls with decreasing roll gaps between them. After a certain amount of cold reduction, the metal becomes so hard that rolling cannot be continued without cracking the strip.

When cold worked, some materials harden more than others. The work hardening factor can be measured and often considered during process and tool design. For example, even a simple 90° bend will increase the strength and the hardness at the formed bend line. Low carbon mild steel with 35,000 psi (240 MPa) yield and over 30% elongation will have a 1 to 2° springback. Other metals (e.g., some zirconium alloy) with the same 35,000 psi (240 MPa) yield and over 30% elongation, will work harden faster, and after the same 90° bend, it will spring back 25°. Figure 6.11 shows the effect of work hardening on the yield strength of a few metals.

Some of the cold worked metals, often called “full hard” or “unannealed,” are used by the industry. Most of the metals, however, are heated to a higher temperature or, in other words, “annealed” before shipping to users. During annealing, above a specific temperature and time, the long, elongated work-hardened grains will dissolve and recrystallize and will become much more soft and ductile. As a result, the high yield, high tensile, low elongation, hardened metal will again be formable and will have low yield, low tensile strength and high elongation after annealing (Figure 6.12).

6.6 Hot Rolling

The annealing and recrystallizing temperature for steels is around 1100 to 1400°F (590 to 760°C), more accurately 1340°F (727°C) for low carbon steels, and for aluminum is about 650–800°F (345–425°C). If metal is plastically deformed above the annealing temperature (e.g., forged or hot rolled), then the hardening caused by the work is immediately removed. Therefore, the mechanical properties of hot worked material are very similar before and after the process, although the size and the shape of the grains change.

Hot working requires less force than working at room temperature. It is also possible to achieve larger thickness reduction at each forming pass. As a result, the rolling of 8 to 10 in. thick cast slabs into plates and coils starts at high temperature and hot rolling continues as long as temperature is above a predetermined level. During rolling, the metal thickness is gradually reduced and the strip gets longer and

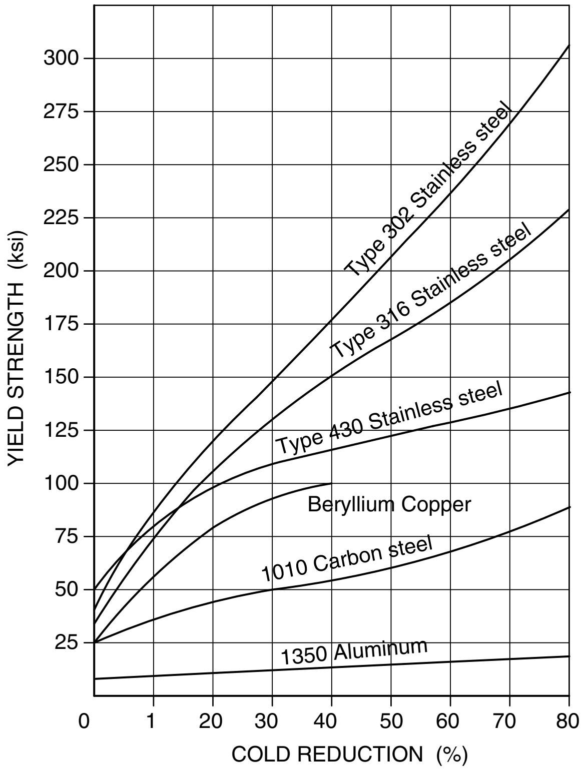


FIGURE 6.11 Typical work hardening rates of different metals.

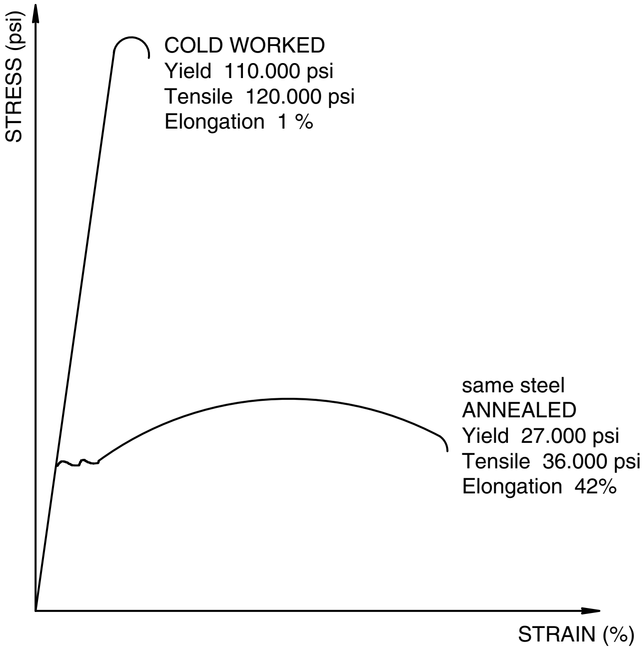


FIGURE 6.12 Stress–strain diagram of the same material cold-worked and annealed.

longer, increasing its surface. After a while, the surface and the related heat loss becomes too large to continue the rolling at an elevated temperature. Cooling is generally the limiting factor for hot rolling steels. Therefore, hot rolled steels are usually available only above 0.070 in. (1.8 mm) in thickness, although some mills are capable of hot rolling down to 0.060 in. (1.5 mm).

6.7 H.R. and H.R.P.O. Steels

All hot rolled steel will have an iron oxide scale on its surface. Iron oxide is very abrasive, and, in many cases, it has to be removed from the surface of the product. The most common industrial method to remove the iron oxide layer is "pickling." During this process, the strip is passed through an acid bath, which dissolves and removes the oxide layer.

Uncoated steels, without any protection, will start to corrode (rust) very quickly. To prevent or at least to retard rust formation, a thin layer of protective oil is applied on the surface of the metal. This type of scale free, oil protected steel is known by the industry as hot rolled, pickled and oiled (H.R.P.O.) steel.

6.8 Cold Rolled Steel

To further reduce the thickness below 0.070 in. (1.8 mm), the scale free steel has to be cold rolled. The work hardening limits the amount of cold reduction but its effect can be removed by annealing. Annealing is usually carried out in a nitrogen/hydrogen environment, which does not cause oxidization or even discoloration. The bright, unprotected cold rolled (C.R.) steel is also susceptible to rusting. Therefore, unless otherwise specified, the surface of the uncoated, cold rolled steel coils and sheets are also protected with oil.

6.9 Carbon Steel

Pure iron (Fe) is not used by the sheet metal industry. All commercially used steels have a small percentage of carbon as well as different impurities picked up by the iron during the steel making process, or have small amount of alloying elements added. Even a very small amount of impurities, such as sulfur (S) or phosphorous (P), can influence (usually reduce) certain properties of the steel. Therefore, these impurities are carefully controlled.

Carbon also has a major influence on several properties. The so-called "mild" steels, with carbon content not exceeding approximately 0.20% can be easily formed and welded, but their hardness and strength can be increased only in a very limited way by heating and quenching (heat treatment).

Steels with higher carbon content (around 0.4 to 1.0%) will have higher yield and tensile strength and lower elongation (Figure 6.13). High carbon steels cannot be welded with the usual processes but they can be heat treated. Many spring steels belong to this group.

The commonly used SAE J403 specifications, such as SAE 1008, 1010, 1020, and so on, refer to the carbon content. The nominal carbon content of the above steels will be nominally 0.08, 0.10, and 0.20%. Forming steels are designated by the SAE J2329 specification; they have similar chemistry to SAE 1006, 1008, and 1010 steels, but are mechanically and thermally processed to retain greater formability then typical J403 grades. Because the carbon content and the mechanical properties are related to each other, designers sometimes specify the carbon content to achieve good formability or good strength. However, steel with controlled chemical composition usually has a slightly higher price tag and does not necessarily guarantee uniform, good formability.

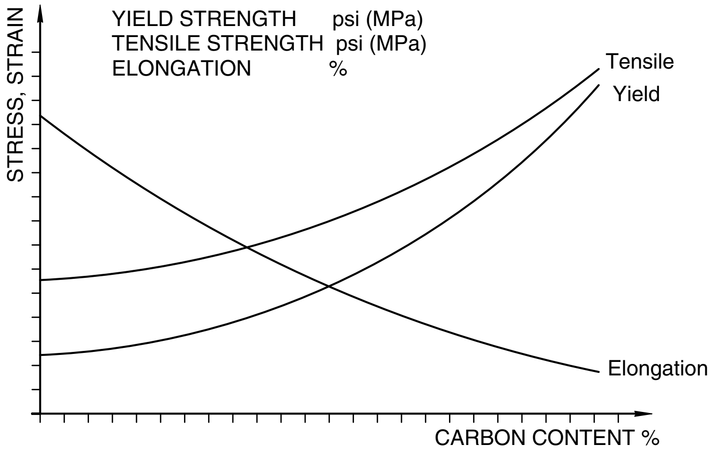


FIGURE 6.13 Influence of the carbon content on mechanical properties of steel.

6.10 Alloyed Steel

6.10.1 HSLA (High-Strength Low Alloy) and UHSS (Ultra High-Strength Steels)

In addition to carbon, several metallic and nonmetallic elements are used to achieve the desired mechanical, corrosion resistance or other properties of steel. In addition to the always present carbon (C), silicon (Si) and manganese (Mn) are the most frequently used alloying elements. Other frequently used alloying elements are:

Chromium (Cr)
Columbium (Cb)
Molybdenum (Mo)
Phosphorus (P)
Titanium (Ti)
Vanadium (V)
Zirconium (Zr)

SAE (Society of Automotive Engineers) standard J2340 describes strengths from 180 to 1500 MPa. These types of steels are shown in Table 6.3.

High strength steels create additional challenges to the roll formers because of their higher strength and therefore greater springback. In some cases, 25° or more overbend is required to achieve a 90° bend.

TABLE 6.3 SAE Steel Designations

Steel Description	Grade Type	Available Strength Grade (MPa)
Dent Resistant Non Bake Hardenable	A	180, 210, 250, 280
Dent Resistant Bake Hardenable	B	180, 210, 250, 280
High Strength Solution Strengthened	S	300, 340
High Strength Low Alloy	X and Y	300, 340, 380, 420, 490, 550
High Strength Recovery Annealed	R	490, 550, 700, 830
Ultra High Strength Dual Phase	DH and DL	500, 600, 700, 800, 950, 1000
Ultra High Strength Low Carbon Martensite	M	800, 900, 1000, 1100, 1200, 1300, 1400, 1500

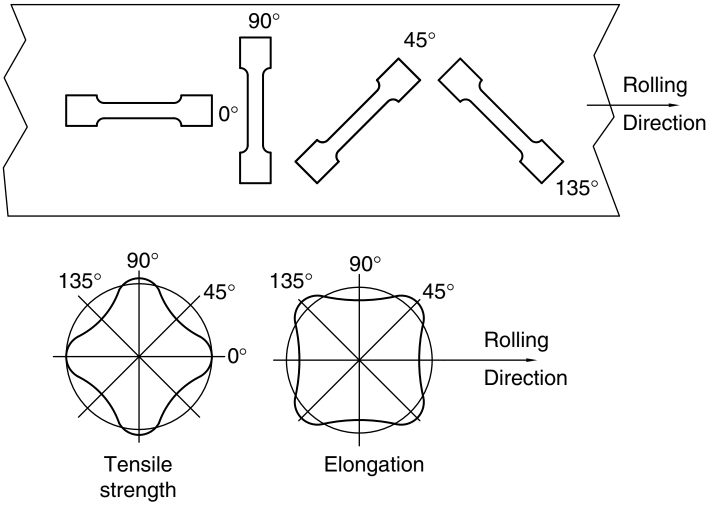


FIGURE 6.14 Mechanical properties of the metal may vary at different direction to rolling.

Continuously annealed steels range from Bake Hardenable steels with 180 MPa (26,000 psi) yield/310 MPa (45,000 psi) tensile strength up to the dual phase grades of steel with 700 MPa (101,000 psi) yield/1000 MPa (145,000 psi) tensile strengths. Maximum yield can be considerably higher than the specified minimum and it can fluctuate from coil to coil or even within a coil.

Mechanical properties are specified and tested in the rolling direction. Properties 90° to the rolling direction can be different from those in the rolling direction. Because roll forming creates the highest strains at 90° to the rolling direction, the variations in the mechanical properties may create undesirable fluctuation in the springback and formability (Figure 6.14). Steel mills are continually working to reduce this variability.

6.10.2 Aging and Drawing Quality Steels

After being cold worked about 2 to 10% (including skin passing), steels have a tendency to "strain-aging." A small amount of nitrogen (about 0.01%) added to the steel increases its strength, but also contributes to the aging process. Within a few days after the small cold deformation, the yield strength will increase. Heat applied in the paint baking process accelerates aging.

Aging can be critical in deep drawing. To prevent aging, aluminum (or other elements) is added to "kill" the process. Killed steels will not

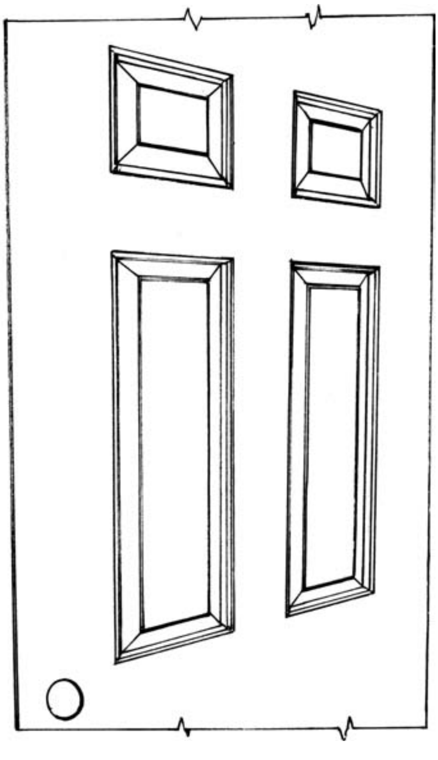


FIGURE 6.15 Door panel with drawn embossments. (Courtesy of Steelwood Door)

age. Different "drawing" quality steels are available as specified in SAE J2329 and are referred to as Grades 1, 2, 3, 4, and 5. Each grade has guaranteed specific levels of formability defined by minimum n value, r value, elongation, and maximum yield strength (ASTM specifications and grades are sometimes used by industries other than automotive. ASTM designations CS, DS, DDS, and EDDS are now used instead of the old DQ, DQSK, DDQSK, and EDDQ descriptions).

Aging has no significant and proven influence on roll forming. Therefore, drawing quality steels are not needed for roll forming. They have to be used only, when the strip to be roll formed is "drawn." Residential garage and entrance doors with decorative rectangular wood imitation embossments (Figure 6.15) are usually have to be made from Grade 2 or 3 (ASTM DS or DQ) steels, otherwise they will crack or wrinkle at the drawn embossments.

6.11 Stainless Steel

By increasing the chromium (Cr) and other elements in the steel, it is possible to make them rust and heat resistant. These so-called stainless steels fall into one of the three major classes, depending on their crystal structure and alloying elements. The three classes are "austenitic," "ferritic," and "martensitic."

6.11.1 Austenitic Stainless Steels

Austenitic stainless steels (200 and 300 series) usually have 16 to 24% Cr, 3.5 to 24 (37)% Ni, 0.8 or 0.25% C and other elements. Austenitic stainless steels are ductile, but work hardening rapidly increases springback and they are usually more expensive than the 400 series steels. The most popular alloys of this group are the 304 and 316 types. Austenitic stainless steels are nonmagnetic under most conditions.

6.11.2 Ferritic Stainless Steels

These types of stainless steels (part of the 400 series) are less ductile than the 300 series alloys, thus they have restricted formability. Some alloys work harden somewhat more than carbon steel. Ferritic stainless steels are magnetic.

6.11.3 Martensitic Stainless Steels

Most of these steels, with the exception of the 403, 410, 414 types, cannot be cold formed. Most martensitic stainless steels are magnetic.

The properties of the stainless steels described in the above three groups are only typical. There is a large variety of stainless steels and their properties fluctuate greatly, depending on alloying elements, cold work, and heat treatment.

6.11.4 Formability of Stainless Steels

Most stainless steel can be formed, similar to the carbon steels, but the followings must be considered:

- Correct specification (including annealed, tempered, half hard, etc.)
- Work hardening properties
- High springback
- More power to form
- Better and different lubrication (better wetting properties and higher pressure resistance)
- High luster surface requires special considerations
- "Orange peel" appearance at the bend lines of some alloys
- Ridging and roping effect at the bend lines of some ferritic stainless steels

TABLE 6.4 Relative Cold Formability of Annealed Stainless Steels

Austenitic		Ferritic		Martensitic	
Material	Rating	Material	Rating	Material	Rating
201	C	405	B	403	B
202	A	429	B	410	B
301	C	430	B	414	D
302	A	430F	N		
304	A	430FSr	N		
305	A	434	B		
309	C	436	B		
310	A	442	B		
314	C	446	C		
316	A				
317	C				
321	C				
347	C				
348	C				
384	A				

A, Excellent; B, Excellent but avoid sharp radii; C, Good; D, Fair; N, Not Recommended.

A good understanding of the effects of cold forming and the metallurgical as well as mechanical properties of stainless steels is essential to successfully roll form the right product. Table 6.4 provides a guideline to the cold forming properties of stainless steels.

6.12 Metallic Coatings

The surface of uncoated (base) carbon steel will be quickly covered by iron oxide (rust). The surface will be unsightly and as more and more iron is converted to oxide, the thickness will be reduced and the strength of the product diminishes. To protect the surface and to prevent rusting of carbon steels, different metallic coatings have been developed. Tin, chromium, zinc, aluminum, and other metals are used for this purpose. Metallic coatings can be applied to the steel surface by dipping the steel into the liquid metal, or by electrolytic process, vapor deposition, hot spray, lamination with fusion bond, chemical bond, or other processes. In all cases, proper preparation and cleanliness of the steel surface is essential.

The most widely used metal for coating steel is zinc. Zinc-coated (frequently called "galvanized") steel is produced by dipping the steel into a molten zinc (or zinc alloy) bath (hot dip galvanized), or it is applied by an electrolytic process (electrogalvanized). Hot dip galvanized steel may have an added thermal treatment immediately after exiting the zinc pot, which creates a zinc–iron alloy coating called "Galvanneal." In the case of hot dipping, the adherence of zinc to steel will depend on the steel and zinc temperature, immersion time, alloying elements and other factors, and the previously mentioned surface preparation. Highly formable Interstitialfree (IF) steel substrate is typically used for hot dip galvanized and Galvanneal, but this coating is available for bake hardenable, solution strengthened, high strength low alloy (HSLA), and dual phase grades as described in SAE J2340. The coating weight (thickness) of the zinc coating is controlled by the distance of the air knives from the coil. In addition to the differences in coating thicknesses, about 16 different types of coatings are used for automotive application and about three to four types for building products. For a further explanation of these processes and coatings, see SAE J1562.

Almost all grades of steel are available with electrolytic coated zinc including some of the very high strength martensitic grades, which are unavailable with hot dip coatings. EG is usually used for thin zinc coatings and in area where a superior painted exposed finish is desirable.

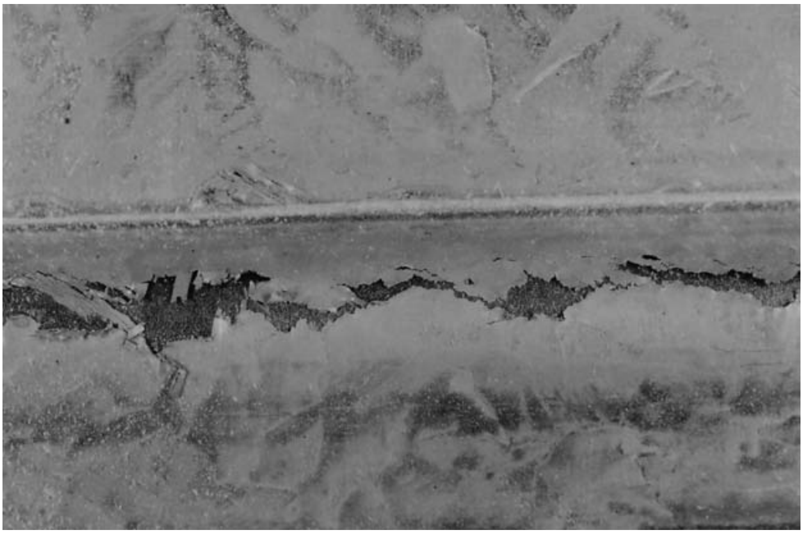


FIGURE 6.16 Zinc flaking off at bend line. (Courtesy of Delta Engineering Inc.)

Zinc-coated (galvanized) steels can be roll formed just as well as uncoated steel, but the zinc pickup on tooling and damage to the coating must be prevented. Zinc pickup is mainly a result of the "cold friction welding" (smearing) effect caused by the speed differential between the rolls and formed strip, accelerated by the roll pressure. It is cumbersome and it can be dangerous to remove the built up zinc from the rolls. The best way to eliminate the zinc build up is to use good lubrication combined with properly designed and set up tools.

In the case of roll forming, there is practically no difference between the hot dipped or electrolytically coated steel if the coating has the proper adherence. Careless metal preparation and incorrect coating procedures can lead to the zinc "flaking off" the product (Figure 6.16). Galvanneal (zinc–iron) coated steels create no problems during roll forming.

Zinc–aluminum alloy (some of them up to 55% aluminum content) and aluminum coated steels behave similarly to the galvanized steel. Metal pickup can be avoided by using the same precautions as recommended for zinc coating — mainly good lubrication.

Aluminum-coated steels can be roll formed similarly to the zinc-coated steels. Application of proper lubricant is important to eliminate aluminum pickup by the rolls.

6.13 Nonmetallic Coating and Laminating

Coil coated finishes are available in wide varieties. Polyesters, epoxy-polyesters, silicon-polyesters, plastisols, urethanes, fluorocarbons, acrylics, and other materials are used to prepaint steels and other metals.

To laminate the surface of metals, polyvinyl chloride (PVC), polyvinyl fluoride (Tedlar), polyethylene, polypropylene, acrylic, and other films are used.

All these painted and laminated metals can be roll formed under proper conditions.

A few difficulties with coil coated materials can be their sensitivity to pressure, cracking of certain types of paints at the bend lines, and the abrasion of some coated surfaces.

Paints used for precoating usually have excellent surface characteristics for roll forming. In most cases, even lubrication is not required because paints are relatively soft and frequently have good lubricity. Roll designers and mill operators must ensure that there is sufficient gap between the rolls and no undue pressure is applied on the coated surface. The polished surface finish of the rolls and other tooling should be free of chips and cracks. Rough roll surfaces may pick up paint and mar the surface.

Paint cracking may occur if less ductile paint or plastic and smaller than the required bending radius are used. Larger bending radius can overcome this problem. If the bending radius must remain small, then preheating of the bend lines in front of the forming rolls can make the paint flexible and elastic enough to be formed without cracking. Depending on the type of paint or laminate, the surface temperature may be raised to 130 to 230°F (55 to 110°C). Coils can be preheated with electricity, gas, or by just passing it through a hot water bath.

On the other hand, paint can be less flexible at low temperatures. Painted coils transported or stored below the freezing point may develop paint cracks if they are roll formed without first warming them to room temperature.

Possible paint cracks on the exposed surfaces must be carefully checked. Almost invisible small cracks at the bend lines will pass water and corrosive atmosphere through and corrosion (white rust or brown rust or other corrosion on metals other than steel) may start during storage or after installation. Correcting problems caused by paint cracking is extremely expensive.

In the case of laminated material, the thickness of lamination should be added to the thickness of material when rolls are designed and installed. For example, rolls designed for 0.036 in. thick material will not be able to process the 0.034 in. thick steel coated with 0.010 in. thick laminate.

Longitudinal scratches caused by the entry guides, straighteners, cutoff dies, or other components can be avoided by making the above items from the right material, providing a good, smooth entry, and avoiding sharp edges.

6.14 Joining Different Materials in the Roll Forming Process

Metals can be combined with other metallic or with nonmetallic materials during the roll forming process. The other material can be adhesive bonded, mechanically joined (folded, pinched, lock seamed), soldered, brazed, welded to (or extruded on) the metal strip. Roll forming of these composites can be successfully accomplished if proper conditions are provided.

6.15 Aluminum

To specify the material just as “aluminum” is one of the most common mistakes made by designers not familiar with metals. There are many different aluminum alloys (as with steels), with vastly different properties. Therefore, it is essential to use the proper designation for aluminum used in roll forming.

6.15.1 Wrought Aluminum Alloy Designations

The mechanical and other properties of the wrought aluminum used for roll forming are influenced by the alloying elements, heat-treatment, and cold work.

The numbering system used by the Aluminum Association standards [381] classifies the commonly used aluminum alloys by their major alloying elements in the following groups:

1xxx	Aluminum min. 99%	Low strength, elastic, good corrosion, and electrical properties
2xxx	Copper	High strength, heat treatable, reduced corrosion resistance
3xxx	Manganese	Medium strength, relatively good corrosion resistance
4xxx	Silicon	Mainly used for castings
5xxx	Magnesium	Good corrosion resistance, reasonable strength
6xxx	Magnesium and Silicon	Good corrosion resistance, moderate strength, excellent weldability
7xxx	Zinc	High strength, low corrosion resistance
8xxx		Other Elements

The 3000 series alloys, such as 3003, 3004, and 3105 (designating different alloys), are the most frequently used alloys by roll formers. Aluminum alloys called “Building Sheets” and other trade names usually belong to this group of alloys.

6.15.2 Basic Temper Designations

F	as fabricated, no mechanical limits specified
O	annealed to achieve the lowest strength, highest ductility, and formability
H	strain (work) hardened by rolling (with or without additional heat treatment)
W	can be formed right after heat treatment, age hardened at room temperature

6.15.3 Temper Designations

T	heat treated, aged at high temperature (with or without strain hardening)
*H*1	Strain Hardened only
*H*2	Strain Hardened and Partially Annealed
*H*3	Strain Hardened and Stabilized by low temperature heat treatment.

A second digit after the above designations indicates a variation of the temper.

-*H*12 one-quarter hard	-*H*32 one-quarter hard (and stabilized)
-*H*14 one-half hard	-*H*34 one-half hard (and stabilized)
-*H*16 three-quarters hard	-*H*36 three-quarters hard (and stabilized)
-*H*18 full hard	-*H*38 full hard (and stabilized)

For three digit designations, such as H112, H364, and others, see the reference literature [381].

Numbers *T1* to *T10* refers to the combinations of hot and cold working, heat treatments, cooling, and aging. The basic treatment depends on the type of alloy and on the properties to be achieved.

Two digits tempers such as *TX51* and others may refer to the stress relieving by stretching (or compressing) process.

The 1000, 2000, 3000, and 5000 series of alloys cannot be strengthened by heat treatment.

6.15.4 Cladding

The good corrosion resistance of the 1000 or other series of alloys can be combined by the high strength of other alloys. Thin layer of the low strength, high corrosion, resistance alloy is metallurgically bonded (hot rolled) on one or both sides of the higher strength but low corrosion resistance alloy. During roll forming, additional care has to be taken not to scratch or damage the soft protective surface of the clad alloys.

6.15.5 Bimetals

Aluminum can also be bonded to other metals such as stainless steel. The combination provides a relatively light weight product with the stainless steel (or other metal) properties. It is not too difficult to roll form these types of bimetals, but more attention must be paid to the forces applied by the rolls. The larger force required to form the stainless steel reduces the thickness of the aluminum. Uneven thickness reduction can create an unacceptable camber, twist, or other imperfections in the product.

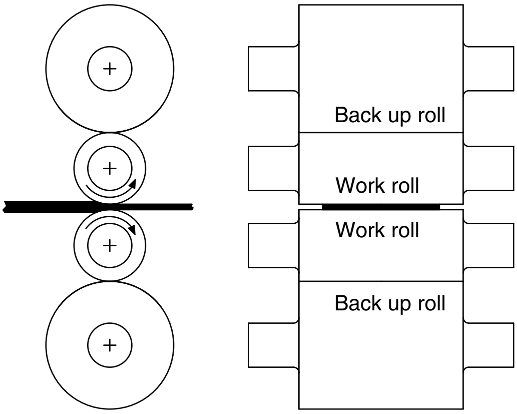


FIGURE 6.17 Reducing metal thickness during hot and cold rolling.

6.15.6 Roll Forming of Aluminum

Roll forming of aluminum is not as difficult as forming steel, but more attention has to be paid to:

1. Careful setting and adjustment of roll gaps
2. Application of the right lubricant to prevent pick up of aluminum on rolls
3. The use of well-designed and finished rolls to prevent surface marks.

The recommended minimum bending radii for aluminum alloys are shown in Table 6.2.

6.16 Other Metals and Materials

Practically all metals that can be formed by other processes can be roll formed. Typical roll formed metals are copper, brass, tin, zinc, titanium, zirconium, and nickel alloys (such as Monel, Hastelloy, Inconel, Invar, etc.) and many other metals and alloys. Owing to space limitations, other metals cannot be listed in this book. However, other reference books and sales information will provide most of the required data to roll formers. Many of these alloys work harden quickly. This increases the springback and can limit the formability. Occasionally stress relieving or annealing is required after or in between roll forming.

Nonmetallic materials can be roll formed too. Thick rubber or plastic coating extruded on thin metal carrier is occasionally "roll formed" after the extrusion process. Certain plastics (e.g., thermoplastics) can also be roll formed.

6.17 Influence of Primary Metal Processes on Roll Forming

For simplicity, the following processes, applied before roll forming and influencing roll forming, are grouped together in this section.

1. Metallurgical Processes to make the metals
2. Hot and Cold Rolling
3. Coating
4. Embossing
5. Slitting.

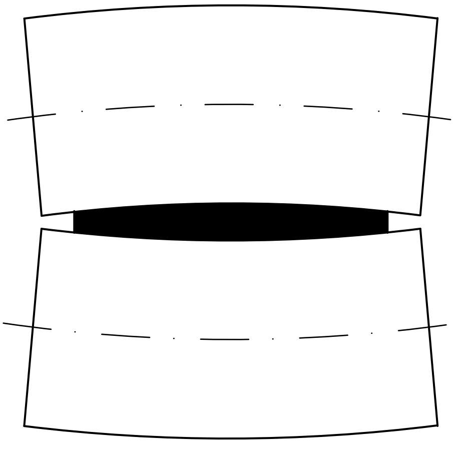


FIGURE 6.18 Rolling load deflects rolls.

6.17.1 Metallurgical Process

It is not within the scope of this book to discuss the processes involved in producing the starting material for coils, strips, and sheets. However, these processes have significant influence on the formability of the metals.

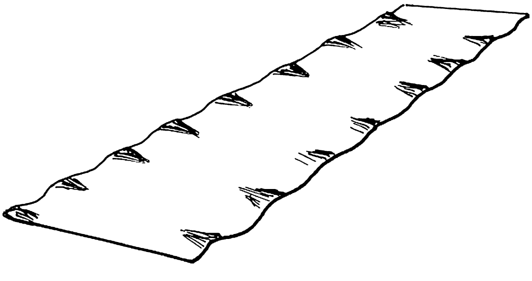


FIGURE 6.19 Thinner and longer edges will be wavy.

6.17.2 Hot and Cold Rolling

The cast metal slabs are usually hot rolled to a minimum practical limit then cold rolled further to reduce their thickness.

Both hot and cold rolling are accomplished by reducing the thickness between pairs of smaller diameter work rolls, supported against deflection by larger back-up rolls (see Figure 6.17)

Regardless of their diameter, the rolls will be deflected by the large forces required to reduce material thickness. The forces can be in the magnitude of a million pounds (500 tons).

If the straight rolls deflect, then the edges will be thinner than the metal at the longitudinal center of the coil (Figure 6.18). The thinner the material gets during rolling, the longer it will be. The thinner and therefore longer edges of the coil cannot "run away" from the center part; therefore, it will take a wavy shape (Figure 6.19). To counteract the deflection, the center of the rolls is grounded to larger diameters, creating a "crown" on the barrel-shaped rolls. If the increase in diameter at the center of the roll is twice the anticipated deflection, then the working side of the roll will become straight under the load (see Figure 6.20). Coil rolled under this condition will have the same thickness at any point.

The actual deflection, however, deviates from the theoretical one. Rolling temperature, uniformity of the starting size, the amount of alloying elements, and the thickness reduction schedule will change the force required for rolling, and thus the deflection. With changing forces, the deflection will fluctuate. If the force is higher than the crown prepared for, then the center of the coil will be thicker. If the actual force is less than the anticipated one, then the center of the sheet will be thinner and the edges will be thicker (Figure 6.21). In the case of thin edges, visible edge waviness, and in the case of thin center, visible center waviness (oil canning) can develop (Figure 6.22). The mills can influence the deflection and produce coils with longer center or longer edges. In most cases, the latter type of coils (thinner at edges than at the center) are produced.

If an "oil canny" sheet is cut in half in a longitudinal direction, then the long center part will create an outward camber in the strip (sheet) as shown in Figure 6.23. If the edges are longer, as is usually the case, the camber will be in the opposite direction (Figure 6.24).

The coil can also be rolled with a camber if, during rolling, one end of the roll gap is larger than the other end (Figure 6.25). Slitting will not remove the camber from the coil.

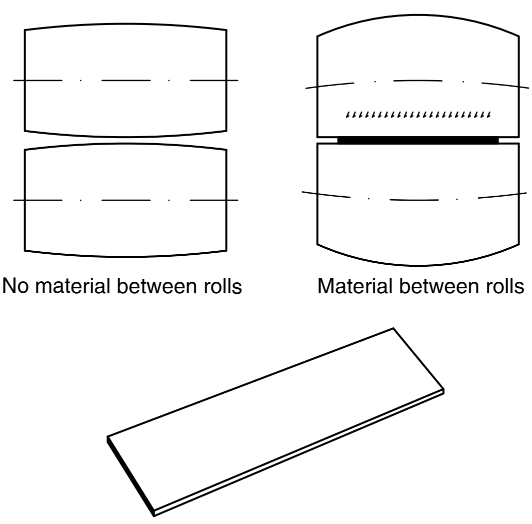


FIGURE 6.20 Deflection compensated by crown on the rolls will result in uniform strip thickness.

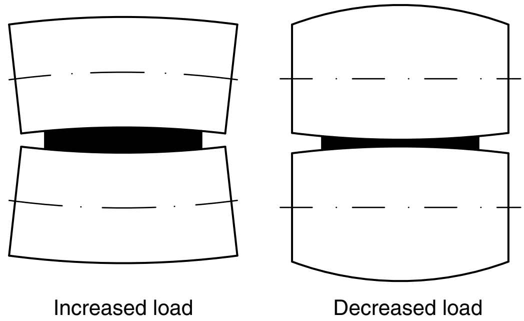


FIGURE 6.21 Roll gap variations caused by increased or decreased load.

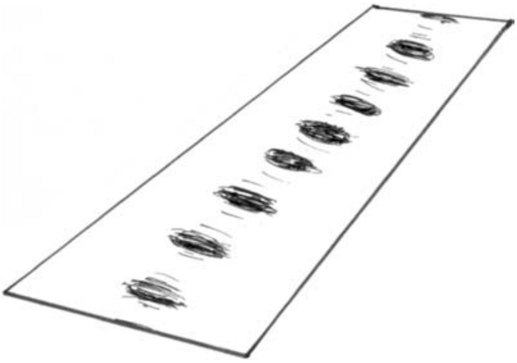


FIGURE 6.22 Thinner and longer center results in center waviness.

6.17.3 Tension Leveled Metal

To provide a flat surface and to eliminate the waviness, the material can be continuously stretched. During this process, the tension (pulling) rolls are running faster than the pay-off rolls. Because this continuous leveling is an additional process, often extra price is charged for this type of product. In most cases, it is not required to tension level the coils for roll forming. In the case of wide, flat products, the usual tension leveling can be detrimental. However, sophisticated leveling (shape control) equipment can induce a predetermined amount of edge or center waviness which is sometimes needed to manufacture straight, flat end products.

6.17.4 Slitting

High speed slitting is the most economical way to cut the wide mill coils into narrower strips. If there is a noticeable difference in thickness within the width of the coil, then during rewinding, the thinner and therefore longer strips will start to sag. The thicker, shorter length, coil segments will remain tight while the thin ones will hang in a loop. In some older slitter installations, 20 to 40 ft deep pits have been built to accommodate these loops. To keep a tension on all recoiled narrow strips and to eliminate the loop, cardboard pieces were placed between the wraps to increase the rewound coil diameter. Newer, better slitting equipment can rewind all the strips under tension and eliminate the dangerous practice of inserting cardboard pieces.

As mentioned earlier, slitting will not eliminate camber in the strip. Actually, dull slitting knives, applying more force than required or creating burr, may induce camber in the formerly straight material.

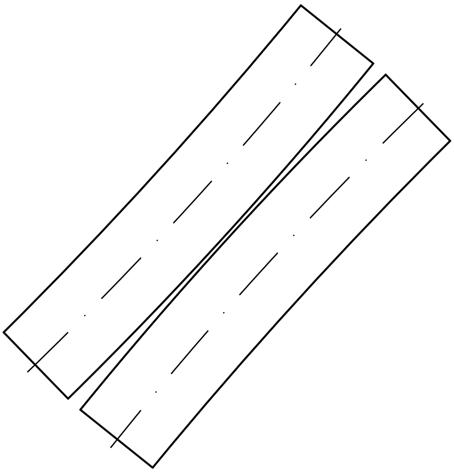


FIGURE 6.23 Slitting straight center wavy (oil canny) coil can result in cambered strips, curving away from the center line.

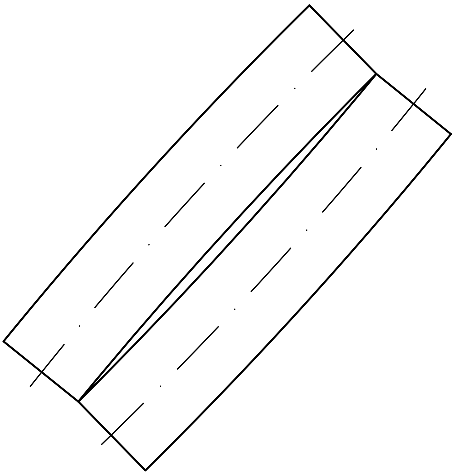


FIGURE 6.24 Slitting straight edge wavy coil can result in strips having camber towards the center.

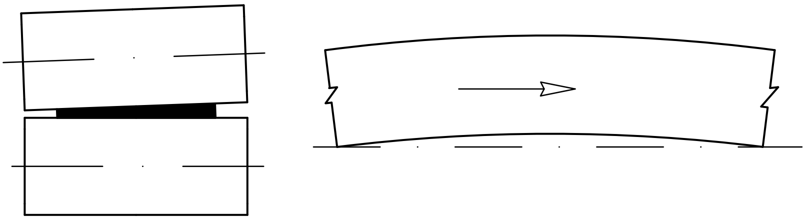


FIGURE 6.25 Nonparallel rolls will produce coils with one edge thicker than the other one. Uneven thickness (length) causes camber in the coil.

TABLE 6.5 Guideline Prices of Different Carbon Steel Strips Compared with the Base Price of HRS

1. HRS (Hot Rolled Steel) Base Price			
Thickness	0.180 to 0.229 in. (4.6 to 5.8 mm)		**HRS Base = 1**
Width	24 to 48 in. (610 to 1220 mm)		
Type	Grade 1 (CS) and Structural		
2. HRS (Hot Rolled Steel) Extras (Typical)			
HRS Extras			Over HRS Base Price
Grade 2 or 3 (DS, DDS)			2.5%
30, 33, 36, 40 ksi min. yield			1.8%
45 ksi min. yield			3.5%
50 ksi min. yield			4.4%
HSLA 40			4.4%
HSLA 65			20.0%
HSLA 80			22.0%
H.R. Pickled and Oiled			8.0%
Width and Thickness Extras			0 to 15.0%
3. CRS (Cold-Rolled Steel)			
			Over HRS Base Price
Thickness	0.028 to 0.063 in. (0.7 to 1.6 mm)	**Base Price**	20.3%
Width	45 to 60 in. (1145 to 1525 mm)		
Type	ASTM A 366		
CRS Extras (Typical)	Over CRS Base Price	Over HRS Base Price	
0.15 in. thick (base width)	3.6%	23.0%	
36 in. wide (base thickness)	15.2%	36.0%	
0.015 in. thick, 36 in. wide	16.8%	38.0%	
Structural ASTM 61 Grade A	2.9%	23.8%	
Structural ASTM 61 Grade B	2.9%	23.8%	
Structural ASTM 61 Grade C	2.9%	23.8%	
Structural ASTM 61 Grade D	6.6%	28.2%	
Structural ASTM 61 Grade E	1.6%	22.2%	
Thickness Tolerance: Tighter	5.1%	26.4%	
Width & Thickness Tolerance: Tighter	0 to 28.6%	20.3 to 54.7%	
HSLA 45 to 50 min yield	10.3 to 13.9%	33.6 to 37.0%	
Electrical	0 to 93.0%	40.0 to 130.0%	
4. Galvanized Extras on Cold Rolled Steel (Typical)[a]			
			Increase over HR Coil Base Price
Thickness	0.023 to 0026 in. (0.59 to 0.66 mm)	**Base Price**	Add 55.7%
Width	40 to 55 in. (610 to 1220 mm)		
Type	Grade 1 (CS) or Grade A		
Galvanized Steel Extras	**Over Galvanized Base Price**	**Over HRS Base Price**	
Grade 2 and 3 (DS)	4.53%	62%	
Grade 4 (DDS)	6.79%	66%	
Grade 5 (EDDS)	9.05%	70%	
Grade B (37 ksi)	0.79%	57%	
Grade C (40 ksi)	2.26%	59%	
Grade D (50 ksi)	5.66%	65%	
Grade E (80 ksi)	2.26%	59%	
Grade F (50 ksi)	6.23%	66%	
HSLA 40 to 120 ksi	6.79 to 19.24%	66 to 86%	
Lighter Coatings:	Deduct	0.22 to 7.0%	55 to 45%
Heavier Coatings:	ADD $0.30 to $7.47	Add 0.68 to 16.91%	57 to 82%
Thicker Products:	Deduct	2.45 to 22.5%	52 to 23%
Thinner Products:	Add	2.4 to 28.0%	60 to 99%

This guideline is based on steel prices from different mills. Other producers may have different ranges and extras.

[a] Galvanized on hot rolled steel base is available at a lower price than shown in this table.

6.18 Guideline to Steel Prices

Basic steel price is usually based on a minimum 20 ton purchased quantity. To compare the prices of different types of steels, the base price of HRS (hot rolled steel) was chosen as price unit 1 (one). Table 6.5 shows the average prices of different types of strip steels in percentage relative to the base hot rolled steel (HRS) price. The percentages shown in this table vary from time-to-time and depend on the pricing policy of different steel mills. However, it provides reasonably good guidelines to the product designers.

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7

Lubrication

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7.1 Tribology of Lubrication

Boundary friction, which is associated with almost all metal forming operations, is caused by the relative movement of two adjacent surfaces under pressure. In the case of roll forming, the relative movement between rolls and workpiece is enhanced by the surface speed differential of the rolls.

7.1.1 Friction

Friction may be defined as the resistance to relative motion between two bodies in contact. Friction is an energy dissipating process, causing the temperature at the interface to rise and, if excessive, can result in surface damage. It will also influence the deformation taking place in the roll forming operation.

The earliest theories suggested that friction was the result of interlocking two rough surfaces sliding along each other. Friction is actually brought on by a large number of variables, such as load, speed, temperature, the materials involved in the sliding pair, and the various effects of fluids and gases at the interface.

The most commonly accepted theory of friction is based on the resulting adhesion between the asperities of the contacting bodies. Tests have shown that regardless of how smooth the surfaces are, they contact each other at only a fraction of their apparent area of contact. Thus, the forming load is supported with few asperities in contact; hence, the normal stress at the asperity junctions is high. Under light loads, the contact stresses may only be elastic. However, as the load increases to some of the levels involved in the roll forming process, elastic deformation of the asperities may take place and the junctions form an adhesive bond (microwelds).

Both the nature and strength of this bond depend on many factors. Among these are the mutual solubility and diffusion of the two surfaces in contact, temperature and time of contact, the nature and thickness of oxide films or contaminants present at the interface, and the presence of a lubricant film.

With clean nascent surfaces (such as those produced by cutting, or in forming operations in which surface extensions are large) and in the absence of any contaminants or lubricant film, the strength of the junctions is high because of cold pressure welding. Consequently, the shear strength of the junction is high, and hence friction is high. As contaminants or lubricants are introduced, or as oxide layers develop (which may take only a few seconds in some cases), the strength of the junction is lowered because, under these conditions, a strong bond cannot be formed. Thus, friction is lower.

Friction force raises the temperature at the surface. The temperature increased with sliding speed, coefficient of friction, and decreasing thermal conductivity and specific heat of the materials. The higher the thermal conductivity, the greater is the heat conduction into the bulk of the workpiece. In addition, the higher the specific heat, the lower the temperature rise is. Temperature rise can be sufficiently high to melt the interface or to cause phase transformations, residual stresses, and surface damage (metallurgical burn).

7.1.2 Wear

Wear is defined as the loss or removal of material from a surface. Wear can take place under different conditions. These may be dry or lubricated wear, sliding or rolling contact wear, and wear by fracture or by plastic deformation.

There are four basic types of wear: adhesive, abrasive, fatigue, and corrosive wear. Generally, the first three types are of interest in metalworking operations, although the last can also occur as a result of tool, die, and workpiece interactions in the presence of various liquids and gases. Particularly in this case, appropriate choices in lubrication chemistry must be made, depending upon the tool and die compositions; otherwise, excessive corrosive tool wear takes place.

7.1.2.1 Adhesive Wear

This type of wear is a result of the junctions sheared during sliding. If the junctions have strong bonds (such as with clean interfaces, under high loads, and with sufficient time to contact between the two bodies), then fracture of the junction takes place either above or below the interface of the asperities. Generally, it is through the softer metal that wrack forms and propagates. Under repeated cycling, the transferred particle becomes a loose wear particle. In severe cases of adhesive wear, the process is called galling, scuffing, or seizure.

For adhesive wear to occur, there must be an affinity (reactivity) for adhesion and welding between the two sliding surfaces. The most severe case of wear occurs between two clean surfaces, under high normal load and in vacuum. The basic role of an effective lubricant is to reduce the tendency for welding of the asperities, either by separating the surfaces with a layer of lubricant or by reducing the shear strength of the interface by forming low shear strength compounds through chemical reactions.

Surface films are of great importance in adhesive wear. Other than the lubricant layer, the surfaces are almost always covered with oxide layers, contaminants, and adsorbed gases or fluids. These films significantly reduce the shear strength of the interface. Thus, the wear observed in practice is generally lower that it would have been otherwise. Oxide films have a significant role in friction and wear. The effect depends on the relative rate at which oxide layers are destroyed during sliding and the rate at which they form. If the rate of destruction is high, then the surfaces are not as well protected and wear is high.

7.1.2.2 Abrasive Wear

In this wear process, material is removed from the surface by scratching and producing slivers and microchips. Thus, the softer the material, the higher is the abrasive wear rate. Also, the higher the load, the higher the wear rate is.

Abrasive wear may be of the two- and three-body type. In the latter, the third body is composed of wear particles or any other hard contaminants (such as those built up in a lubricant) that are trapped between the two sliding bodies. This mechanism may also be referred to as erosive wear. This type of wear is important in metalworking processes and in the maintenance of equipment. To reduce the buildup of oxides, metal chips, or other metallic particles, periodic inspection, filtering, or changing the lubricants is good practice.

7.1.2.3 Fatigue Wear

This type of wear is generally called surface fatigue or surface fracture wear. It is a consequence of cyclic loading of an interface between the tool or die and the workpiece. Cracks develop on the surface over a period of time by a fatigue mechanism, resulting either from mechanical forces or from thermal stresses (thermal fatigue). In either case, material is removed from a surface (usually the tool or die) by spalling or pitting, whereby cracks coalesce by joining each other below the surface.

The role of lubrication in fatigue wear is complex. Lubricants reduce friction and hence reduce the level of stresses that could cause fatigue failure. On the other hand, if a crack develops because of some mechanism or cause, the fluid penetrates the crack by surface tension. During subsequent loading cycles, the fluid is trapped and, because it is incompressible, high hydrostatic pressure in the crack opening develops. This, in turn, propagates the crack farther into the body of the tool or die. Pitting, for example, does not occur in unlubricated interfaces unless chemical attack takes place.

7.1.3 Lubricating Mechanisms

It is apparent from the foregoing discussions that friction and wear can be reduced or eliminated by keeping the sliding surfaces apart from each other. Whereas in machine elements, such as lubricated journal bearings and air bearings, this requirement may be fulfilled easily, the loads and speeds involved in metalworking and the geometry of the tool, die, and workpiece interfaces are generally such that they do not readily permit the existence of a lubricant film. In this section, the major lubricating mechanisms of interest to metalworking processes are described.

Lubricants are also applied as coolants to dissipate the heat generated by friction or forming. It is also used to flush away particles such as iron oxide and slivers. However, the primary function of the applied fluid is lubricating, therefore, the term “coolant” is not used in this text.

7.1.3.1 Thick-Film (Hydrodynamic) Lubrication

In this area of lubrication (also called full-fluid film), the two surfaces are completely separated from each other by a continuous fluid film. The thickness of this film is about 10 times the magnitude of the surface roughness of the mating surfaces. The fluid film can be developed either hydrostatically (by entrapping the lubricant) or, more generally, by the wedge effect of the sliding surfaces in the presence of a viscous fluid at the interface. Thus, in this type of lubrication, the bulk properties of the lubricant (especially viscosity) are important; chemical effects of the lubricant on metal surfaces are not significant.

In thick-film lubrication, the loads are usually light and the speeds are high. The coefficient of friction is very low, generally between 0.001 and 0.02. There is no wear, except from any foreign matter (third body) that may have entered the lubricating system. This type of lubrication does not generally occur in metalworking processes, except in isolated regions at die-workpiece interfaces with high viscosity lubricants and at high operating speeds.

7.1.3.2 Mixed Lubrication

The film thickness in thick-film lubrication can be reduced by decreasing the viscosity (such as owing to temperature rise), decreasing the sliding speed, or increasing the load. The surfaces become close to each other and the normal load between the tool or die, and the workpiece is supported partly by the fluid film in hydrodynamic pockets in the surface roughness of the interfaces and partly by metal-to-metal contact of the surfaces. This is generally referred to as mixed lubrication and also as the thin film or quasihydrodynamic regime.

The film thickness is less than three times the surface roughness; the coefficient of friction may be as high as about 0.4 (thus, forces and power consumption may increase substantially), and wear can be significant. There is an optimum roughness for effective lubricant entrapment, with a recommended roughness of usually 15 μ. The hydrodynamic pockets also serve as reservoirs for supplying lubricant to those regions at the interface that are starved for lubricants.

7.1.3.3 Boundary Lubrication

In this type of lubrication, a thin layer of lubricant film physically adheres to the surfaces by molecular forces, such as van der Waals forces, or by chemical forces (chemisorption). Typical boundary lubricants are oils, fatty oils, fatty acids, and soaps. Boundary films can form rapidly on clean surfaces, although reactivity on some metals such as titanium and stainless steel is very low; lubrication may then be enhanced by the formation of boundary films on tool and die surfaces instead of on the surface of the workpiece.

An important distinction is that, unlike in full-fluid film lubrication, where the bulk properties of the lubricant (such as viscosity) are important, in boundary lubrication, the chemical aspects of the lubricant and its reactivity with metal surfaces are important; viscosity has a secondary role. In the boundary lubrication area, the coefficient of friction usually ranges from 0.1 and 0.4, depending on the strength and thickness of the boundary film. Boundary lubrication is often observed and practiced in metalworking operations.

Wear rate in this regime depends on the rate at which films are destroyed by rubbing off, or by desorption owing to excessive temperature generated during the metalworking process. If the protective boundary layer is destroyed, then friction and wear will be high. The adherence and strength of this film is therefore a very important factor in the effectiveness of boundary lubrication. The role of pressure, speed, and viscosity on film thickness should also be recognized.

7.1.3.4 Extreme Pressure Lubrication

In this sector of lubrication, the surface of the metal is activated chemically by irreversible chemical reactions. These reactions, involving sulfur, chloride, and phosphorus in the metalworking fluid, form salts on the mating metal surfaces. These surfaces prevent or reduce welding of the asperities at the interface even under high die-workpiece contact pressure, hence the term "extreme pressure" (EP). Furthermore, because of their low shear strength, these surface films also reduce friction.

As temperature increases, however, these films may break down, the temperature for breakdown depending on the particular EP additive (used either singly or in combination, such as both sulfur and chlorine) and the composition of the metal surfaces. When the film breaks down, metal-to-metal contact takes place, with a subsequent increase in friction and wear. However, the protective films of sulfates and chlorides form again with relative ease, especially on clean new surfaces. Air, oxygen, humidity, and water also have important effects on extreme pressure lubrication.

7.1.3.5 Elastohydrodynamic and Plastohydrodynamic Lubrication

We have not yet considered the deflections and distortions the tools and dies may undergo as a result of to the stresses encountered in metalworking operations. It has been shown that owing to the finite modulus of elasticity of materials, these deflections can be sufficiently extensive to alter the geometry of the die-workpiece interface, thus affecting the stresses, contact areas and geometry, and pressure distribution. Hence, the term "elastohydrodynamic" (EHD). Another factor is the increase in viscosity (and even solidification) of lubricants with pressure. This, in turn, helps develop hydrodynamic films, resulting in an increase in film thickness.

An extension of EHD is plastohydrodynamic (PHD) lubrication. In this regime, encountered in such processes as drawing and strip rolling, the lubricant is entrained or entrapped at the converging gaps in the die-workpiece interfaces. Thus, a full-fluid film is developed with a large drop in friction and wear.

These phenomena are particularly important in processes in drawing and in concentrated contacts such as cold rolling of thin strip, because of the influence of small changes in the relative interfacial dimensions on forces and deformation geometry.

7.1.4 Role of Surface Tension and Wetting

In addition to the lubricant viscosity and its chemical properties in reaction to the workpiece and die materials, the surface tension and wetting also play an important role in lubrication. Wetting is a phenomenon related to surface tension, which is a manifestation of surface energy.

Wetting characteristics of a lubricant — that is, how well the lubricant spreads itself over the surface of the workpiece as a continuous film — is an important aspect of lubrication. There may be situations, however, in which it is desirable for the lubricant to remain in a certain area of the tool-workpiece interface. Watch manufacturers, for example, have recognized the need for nonmigrating (nonwetting) lubricants for pivot point in a watch.

The shape of a drop of fluid (such as metalworking lubricant) on a solid metal surface depends on the interfacial tensions between the metal, fluid, and air. The angle that the periphery of the droplet makes with the surface is called the contact angle. The smaller this angle is, the better the wetting characteristics of the fluid.

Wetting in metalworking fluids is improved by the addition of wetting agents, such as alcohols and glycols, or by increasing the temperature. It is also found that wetting is improved by increasing the surface roughness.

It can be seen from the foregoing discussion that lubrication in metalworking involves different mechanisms, depending upon the chemistry of the tool-lubricant-workpiece interface, the method of lubricant application, and the geometry of the process, as well as the mechanics of the operation. Furthermore, the lubrication mode often varies during the metalworking cycle, depending upon the changes in the speed of the process as well as the amount of deformation and attendant pressures and stresses involved.

7.2 Selection of Lubricants

There are five different categories of families of roll forming lubricants being used today in performing operations in roll forming on the various surfaces and materials. The lubricant chosen must provide good productivity and also meet the environmental restrictions imposed on plant operations by the local, state, and federal agencies.

The different types of roll forming lubricants, including their reactive physical and chemical properties for each category are listed below and summarized in Table 7.1:

1. Evaporative compounds
2. Chemical solutions (synthetics)
3. Microemulsions (semisynthetics)
4. Macroemulsions (solubles)
5. Petroleum-based lubricants

7.2.1 Evaporative Compounds

Evaporative lubricants or vanishing oils are widely used roll forming lubricants. This group is quite flexible in its physical properties. The wetting capabilities can be adjusted or modified to suit the

TABLE 7.1 Comparison of Roll Forming Lubricants (Courtesy of Tower Oil & Technology Co.)

Function	Evaporative Compounds	Chemical Solutions (Synthetic)	Microemulsions (Semisynthetic)	Macroemulsions (Emulsion)	Oil-Based (Solutions)
Reduce friction between tool and workpiece	3	3	3	2	1
Reduce heat caused by plastic deformation transferring to the tool	1	1	2	2	5
Reduce wear and galling between tool and workpiece due to chemical surface activity	4	1	2	2	4
Flushing action to prevent buildup of dirt on tooling	1	1	2	3	4
Minimize subsequent processing costs welding and painting	1	1	2	4	5
Provide lubrication at high pressure boundary conditions	4	3	3	2	1
Provide a cushion between the workpiece and tool to reduce adhesion and pick-up	4	4	3	2	1
Nonstaining characteristics to protect surface finish	1	1	2	3	5
Minimize environmental problems with air contamination and disposal problems	4	1	2	3	5

Note: 1, Most effective; 5, Least effective.

severity of the roll forming operation. The drying rate of the lubricant can also be controlled (depending on the evaporative carrier). On heavy-duty evaporative applications, the extreme pressure additives can be added to provide additional protection to both tooling and piece part. Evaporative lubricants are generally not cleaned from the piece part and usually require no degreasing. Evaporative lubricants can be easily applied by using the roller coater method. They can also be applied by using the proper type of airless spray system. Evaporative compounds, however, should not be recirculated. This family of lubricants is ideal for painted, coated, vinyl, and galvanized surfaces as well as nonferrous and ferrous materials.

Special formulations of evaporative lubricants can be used to provide for long-term rust protection on appliances, furniture, and automotive components. In many instances, the same specialized roll forming lubricant can be used not only to produce the part, but also to provide long-term rust protection from the applied lubricating film.

7.2.2 Chemical Solutions (Synthetics)

Chemical solutions (synthetics) are one of the fastest growing roll forming lubricant family. They are economical, environmentally safe, easy to handle, and are ideal for use on coated, galvanized, cold roll steel, aluminum, and in some instances, stainless steel.

Chemical solutions allow for easy welding without prior cleaning and can be used for other secondary operations such as punching, cutoff, and even drilling and tapping.

Chemical solutions are homogeneous mixtures, which are formed when solid, liquid, and gas are completely dissolved in a liquid called the solvent. These solutions (also called "synthetic fluids" or "chemical fluids") do not contain oil, only water-soluble corrosion inhibitors, wetting agents, lubricants (complex esters), biocides (fungicides), defoamers, and sometimes extreme pressure agents.

There are several different types of chemical solutions available. There are soap-type solutions for heavy-duty roll forming. Extreme pressure-type solutions are used for high strength alloys and the nonionic types are excellent for roll forming aluminum and coated components.

Chemical solutions can be applied by roller coater, sprayed, or used in properly designed recirculating systems.

7.2.3 Microemulsions (Semisynthetics)

Sometimes, a roll forming operation requires a lubricant that provides excellent flushing, cooling, and improved lubricating qualities. Microemulsions are ideal for use on galvanized, hot rolled, cold rolled, and stainless steel. Microemulsions provide some film strength from the combination of emulsifiers, water-soluble corrosion inhibitors, wetting agents, organic and inorganic salts, and sometimes extreme pressure agents.

Microemulsions are emulsions in which the dispersed particles are in the range of 0.01 to 0.06 μm. These emulsions are usually translucent or transparent in appearance. Their small particle size provides excellent penetration and cooling for various types of roll forming.

Microemulsions can be sprayed, roller coated or used in a flood-type coolant system.

7.2.4 Macroemulsions

Macroemulsions (sometimes misleadingly called “soluble oils”) contain an oil-based lubricant, such as a mineral or compounded oil in the form of suspended droplets, which have been dispersed with the aid of special chemical agents called emulsifiers. The emulsified oil droplets are large enough to make the made-up lubricant milky (or sometimes translucent) in appearance. The action of emulsions as lubricants can be close to that of the dispersed phase. Emulsions can also be formulated to include higher levels of extreme pressure agents or barrier films (polymers, fats, etc.) for heavy-duty operations. They are generally milky white in appearance. Macroemulsions are generally used in heavy-duty roll forming of structural members, shelving, automotive, and furniture components.

7.2.5 Petroleum-Based Roll Forming Lubricants

This family of forming lubricants provides manufacturing with widest range of choices of various lubricant properties both chemical and physical in nature.

The primary vehicle in the make-up of most petroleum-based forming lubricants is the blending oil (which can be of varying viscosities). Additional physical properties such as fats, polymers, and wetting agents can also be added. If necessary, chemical extreme pressure agents such as sulfur, chlorine, and phosphorous can be added to the formulation.

In special cases, added rust prevention can be provided and cleaning inducers can be included to provide for easier cleaning.

Petroleum-based lubricants will continue to be used in roll forming on a selective basis. Cosmetic-type piece parts of stainless steel and some heavy-duty formed sections may require petroleum-based lubricants.

7.2.6 Additives

Properties of lubricants are adjusted and made suitable for specific applications by additives. Additives can improve lubricating properties, protect metal surfaces, as well as perform many other functions.

Rust or corrosion inhibitors are usually nitrates or phosphates. Extreme pressure additives are sulfur, chlorine, or phosphorus compounds. EP additives reduce the cold welding of metals under pressure and prevent metal “buildup” but may reduce lubricating properties. Additives, such as esters, animal fats and fatty acids are added to oils to reduce surface tension or make it spread better. The synthetic-type lubricants are modified with phosphorus compounds or other chemicals, to act as detergents. The reduced surface tension allows the lubricant to reach the contact area more evenly and quickly.

7.3 Surface Properties of Formed Material

7.3.1 Steel

When forming and lubricating the many types of cold rolled steel, there are two factors that have a direct bearing on the choice of lubricant; they are mill oil and foreign particulate such as scale, oxide, and rust. For example, the presence of mill oil will interfere with the optimum adherence of evaporative compounds, chemical solutions, or water-soluble systems. Another factor is that mill oil is a source of generated waste that should be controlled and minimized. Sometimes, the best answer is to use a chemical solution (synthetic), which will reject the mill oil in a properly designed clarification system. The other alternatives are to use a petroleum-based lubricant over the mill oil or order the material dry.

Another contaminant to contend with on all materials (cold rolled, hot rolled, galvanized, aluminum, and even stainless) is the presence of scale and oxide generated from these surfaces during the forming process. The metal fines not only interfere with the rolls and piece part appearance, but are a source of hazardous waste that has to be controlled by removal before entry into the roll former (by brushing, spraying, and prior cleaning).

It is important that under the above conditions the lubricant chosen has the physical capability to flush the metal particles from both the roll and piece part surfaces. The accumulation of metal particles can be controlled with a properly designed central reservoir (see Section 7.5).

When flushing and penetration are required on either cold rolled, hot rolled and aluminized surfaces, chemical solutions (synthetics) or microemulsions (semisynthetics) are the best choice in order to obtain clean roll formed components (see also Table 7.2).

TABLE 7.2 Roll Forming Lubrication Guide

Material Being Formed	Evaporative Compounds	Chemical Solutions (Synthetics)	Microemulsions (Semisynthetics)	Macroemulsions (Water Solubles)	Petroleum-Based Lubricants
Electro galvanized and hot dip galvanized	X	X	X	X	X
Cold roll steel	X	X	X	X	X
Hot roll steel	X	X	X	X	X
High strength alloy steel	X	X	X	X	X
Stainless steel	X	X	X	X	X
Aluminum	X	X	X	X	X
Paint or lacquer	X	X	X	N/A	N/A
Vinyl coated	X	X	X	N/A	N/A
Lubrication rating	1	1	1	2	3
Type of protection corrosion (indoor)	N/A	2	2	2	1
			Method of application		
Spray					
Roll coat	X	X	X	X	X
Drip	X	X	X	X	X
Flood	X	X	X	X	X
			Method of cleaning		
Alkaline	N/A	X	X	X	X
Solvent	N/A	N/A	N/A	N/A	X

Notes: "X" is suggested usage, application and cleaning methods. Ratings: 1, Excellent; 2, Very good; 3, Good; 4, Fair; 5, Poor; N/A, Not applicable.

7.3.2 Galvanized Steel

There are various forms of galvanized coated materials available for the roll former to fabricate. A partial list would include hot dip, electrogalvanized, galvalum, galvaneal, and zincrometal. One common role in lubrication for galvanized materials is to flush the generated metal fines with the proper choice of application technique and lubricant.

Light lubricants with excellent wetting are preferred to prevent roll buildup and provide clean parts. Generally, evaporative, chemical solutions, and microemulsions perform this task well on electrogalvanized, galvalum, and galvanneal surfaces. However, galvanized material, hot dip, or electrogalvanized should be closely checked, especially when a chemical solution or water-soluble lubricant is to be used. The water source first must be analyzed to see if it will provide good coolant integrity and stability — the actual components of the lubricant to be used should be looked at on a chemical and physical basis. Another added safeguard is to perform humidity cabinet tests to screen out lubricants, which fall short in rust protection. Many times in spite of all the precautions and safety checks, “white rust” may still occur (see Section 7.7.7).

7.3.3 Nonmetallic Coated Metals

Each type of coating such as vinyl, mylar, and paint has its own special surface properties. It is imperative that lubricant properties be checked in relation to each type of coating to prevent such occurrences as blush marks, peeling, and blistering. Evaporative lubricants and chemical solutions are ideal for use on most coated surfaces.

7.3.4 Stainless Steel

Stainless steel is harder to lubricate than cold rolled because of its tight surface integrity (lower porosity) and higher tensile strength. Higher energy levels are needed to form it, along with its spring-back properties, which make it a candidate for pressure-resistant lubricants that will not wipe off during roll forming.

Lubricants that perform well on stainless must have excellent wetting and polarity along with some extreme pressure protection to resist wipe off. Heavy-duty evaporative compounds, “EP”-type chemical solutions and heavy-duty solubles perform well on 200, 300, and 400 series stainless steel. “Static tests” should be made with your chosen lubricant to see if you indeed have enough wetting and adherence.

7.3.5 Aluminum

When roll forming aluminum, the selection of the newer chemical solutions can be a wise choice. These new extra clean solubles are low in viscosity and have unusually good penetration and polarity to keep the metal fines from packing and adhering to tool surfaces. They also help to keep the aluminum well lubricated and clean in appearance. Evaporating compounds are also being used successfully for roll forming aluminum. Microemulsions (semisynthetics) can also provide the necessary flushing and penetration needed for roll forming aluminum.

Foreign metal particles, such as steel, copper, bronze, left on the surface of or embedded in the aluminum will cause corrosion. Therefore, it is recommended that recirculated lubricant, which has been previously used in roll forming other metals, is not used.

7.3.6 Copper, Bronze, and Brass

Several water-soluble synthetic or occasionally water-soluble oil lubricants used to roll form aluminum are applicable for copper based metals. High penetrating, high wetting, properties are preferred.

7.4 Lubricants for the Secondary Operations

More and more roll forming lines are integrated with other in-line operations such as prenotching, cutoffs, and postnotching.

7.4.1 Pre- or Postnotching and Punching

It is not uncommon to use the same lubricant for the prenotching operations that is being used in roll forming. This can often lead to difficulties, because the prenotching can be, and often is, a more severe operation than roll forming. The shortened tool life in this operation can slow down an entire hi-speed roll forming line. Generally, it is much better to look at the prenotching as a separate metal forming operation and choose a lubricant accordingly. Water-soluble materials in heavier concentrations can be quite satisfactory in performing this function.

7.4.2 Cutoff

Another area in secondary operations is the cutoff die. In most slug types of double shear blade cutoff dies, it is advisable to look at the specific operation and choose the lubricant to meet this need. Heavy-duty, superwet, soluble compounds are excellent for blade cutoff dies, and they are also used in heavier strengths than for normal roll forming operations.

The tooling material used for cutoff blades are generally D-2, M-2, and CPM 10 V. The spray method of applying cutoff is strongly recommended, because it provides a positive lubricating film on an automatic basis and is safe and economical.

On single shear or crop-off dies, the tool life problem is generally not as severe as with the blade cutoff dies. However, it is advisable to grease the blade guides with an EP-type moly grease about once per week or more often if it becomes necessary.

7.4.3 Other Postforming Operations and End Use

Operations following roll forming and final application in assembly or erection can influence or restrict the type of lubricant used. This point will be illustrated by a few examples:

1. Painting after forming requires either a dry surface (i.e., evaporating lubricants) or compatible solvents. It is usually recommended to abstain from silicon type lubricants.
2. Water-soluble lubricants, adhering to the surface of the product (especially if trapped by nesting configuration and stored for prolonged periods), can cause corrosion, rusting on “black” steel, white rust on galvanized steel, and staining on aluminum.
3. Lubricants trapped in beads or grooves can create explosion hazards if products are to be hot-dip galvanized after forming. Flash point and flame spreading of lubricants should be checked when products are welded or heated after forming.
4. Oiled slippery roof sheets, installed at slope, and similar applications can create safety hazards during erection.
5. Drying oil or tacky lubricant, acting as an adhesive, can make separation of nested product difficult.
6. Lubricants applied for products subsequently used in direct contact with foodstuff such as grain bins, food containers, and so on, must be free of harmful materials and usually must have health authority approval.
7. Oily, nonevaporating lubricants on office partitions, door frames, and similar products may stain carpets and floors.
8. In line- or postforming, piercing adhesive bonding, foaming, or welding may require special lubricant.

7.5 Application Techniques

In roll forming, there are generally four different methods used in applying lubricant. They are drip, roller coater, recirculating systems, and airless spray. The merits of each are now considered in turn.

7.5.1 Drip

Chemical solutions, soluble oils, and evaporating compounds can be applied by using a drip lubricator in conjunction with some type of wiper consisting of a felt pad, open cell foam, rug material, or packing. Drip lubricators by themselves are not positive enough to provide an adequate and continuous film of lubricant. It should be noted that containers feeding the drip lubricator should be large enough to contain at least an hour's supply of lubricant. Lubricant may be applied to the strip or to the top and bottom rolls.

7.5.2 Roller Coat

The roller coater method of applying lubricant is gaining in popularity. This technique consists of a small movable tank and pumping unit, which feed a wiping head or roller with lubricant. The thickness and the amount of lubricant can be regulated, and the excess flows back to the reservoir. When lubricating precoated or polished materials with a roller coater, it might be advisable to use polyurethane or neoprene rolls to make sure the working surfaces are not scratched or marked. Steel rolls can sometimes cause problems on coated surfaces.

In many instances, roller coaters by themselves may not produce enough lubrication film to flush out particles generated by aluminum, galvanized, and hot roll. Sometimes, a sprayer installed in the critical forming areas where buildup may be occurring can flush out unnecessary particles.

Another problem that can occur when applying lubricant (especially on wide stock) is a result of material that has a "crown" condition. Here, the roller may only lubricate the high spots, leaving the outside edges without lubricant. A similar problem may occur on wavy stock. A soft roller can help in adjusting itself to this crown or wavy condition.

7.5.3 Recirculating Systems

7.5.3.1 Purpose of Recirculating

When roll forming heavy gauge and cold rolled and hot rolled steel (especially with scale), the recirculating system of applying lubricant is usually the best approach. Here, sufficient amounts of lubricant not only have to protect the rolls, but the scale and metal fines that are generated by the roll forming process are flushed off the tooling and into the reservoir. It then follows that the use of baffles, settling tanks and filters help collect large quantities of contaminants and metal fines, helping keep the coolant relatively clean. Magnets can be extremely helpful in keeping the amount of metal being recirculated down to a minimum.

7.5.3.2 Lubricant Tank Design

The function of the closed loop lubricant reservoir is to clarify and remove the foreign materials and process contaminants being generated by the roll forming operation.

The capacity of the tank should be 5 to 10 times the pump capacity of the recirculating pump (e.g., a system with a 10 gallon per minute pump should have a 50 to 100 gallon tank). This capacity allows time for foreign particles to settle out and for oils and greases to be removed by skimming, and so on. It is essential that the reservoir contains two baffles, a skimmer, and some form of filtration such as a bag filter along with magnets to remove metal particles.

In larger operations, many plants have a clarification area where tanks are brought in for cleanup and returned to their respective machines. In this instance, the reservoirs are usually the quick change type, retrofitted for easy removal, and return after being clarified.

In general, most in-machine coolant reservoirs are too small and unyielding to provide for access and any form of clarification. Installing floor tanks away from the roll former itself to provide for easy access for both cleaning and inspection is recommended for all roll forming mills.

Proper housekeeping of recirculating systems is very important; it may make the difference between good and poor tool life. The control of any water-soluble solution concentration used in roll forming cannot be overlooked, or even taken too lightly. Once the proper mix or strength of solution has been established, this particular concentration should be rigidly maintained. To check the strength of water soluble, a refractometer can be used. Premixing larger quantities of coolant and storing them in either 55-gal (220-l) drums or standby tanks can also be very beneficial. Too high a mixture is wasteful and does not allow proper settling or scale removal. Light strength mixtures can bring on poor tool life, rusting or both.

Preliminary planning of a recirculating lubricating system for a roll forming line should take into account many factors. The coolant system capacity should provide a 5-min lubricant cycle time if possible, with a 3-min cycle as the minimum, in order to allow for cleaning and conditioning of the coolant or lubricant. Sizing the systems storage tank at 5 to 10 times the rated capacity of the coolant delivery pump is a good rule.

7.5.4 Airless Sprayers

The new type of airless spray systems can be used successfully to act as auxiliary units on specific forming stations, to reapply lubricant at some critical point in the process, and on cutoff die lubrication. These units work well with solubles, light oils, and evaporating compounds and are quite reliable.

The spray pattern obtained with the use of airless spray can be either round or fan shaped. Owing to the various spray patterns available, it is an excellent method for spot lubrication, either lubricating the stock before it enters the die or in the die itself.

A modern, airless, spray system does not produce mist or fog that results in overspray problems. On the contrary, it can be precisely directed at a target area in the die and is timed to operate in conjunction with the equipment cycle.

Spray systems can also be used for prenotching and punching operations. A typical airless setup for presses consists of an intensifier assembly (piston and barrel), a check valve, a lubricant reservoir of the required size, the necessary number of nozzles needed to cover a particular piece of operations, and an air valve to activate the unit on each stroke of the press.

7.6 Preparation and Maintenance of Lubricants

7.6.1 Preparation of the Lubricant

Before starting to use any roll forming lubricant, one must ensure that the equipment and the recirculating systems or coolant tanks are clean. Even a new system may require a flushing charge to clean out paint chips, rust, scale and other debris that are bound to accumulate during shipping, storage, assembly, and setup.

When starting up the roll forming equipment with a new lubricant in a used or dirty system, attention should be paid to the following. First of all, changing lubricants without cleaning the system can be risky. Many of the systems existing contaminants can harm your newly chosen lubricant. In most cases, the startup lubricant in a dirty system is rapidly contaminated and has to be replaced anyway, so it is better to do it right the first time.

The system, either new or old, should be cleaned with a detergent or cleaner that is compatible with the components in the system.

The lubricant to be used should be properly mixed and identified the same way each time. A premixing valve may be used for this purpose, or a separate tank or barrel set aside with the proper concentration of lubricants already made up. Many plants use central systems for this reason, because they can control the mixture of their lubricants more easily.

7.6.2 Maintenance and Control of Lubricant

Too often, the mixed lubricant is placed in the tank, mixed properly the first time, and subsequently forgotten about. There are certain long-term maintenance procedures that must be followed:

1. The make-up lubricant should always be added already mixed in the correct water.
2. The concentration of the lubricant should be checked periodically — at least once per week by using a titration kit or a refractometer for this purpose. Both of these methods take very little time and are easy to perform.
3. The lubricant has to be kept clean. Magnets and filters should be installed where metal fines or foreign particles are being generated. Tramp oil should be skimmed off preferable with an automatic skimming system. Tramp oil will not only increase the possibility of bacterial buildup in the recirculating systems, but also draws off any emulsifier that may be riding on top of the lubricant, thereby weakening its lubricant qualities. This phenomenon of drawing off the emulsifier from the lubricant package does not generally occur with the newer synthetic water-soluble roll forming lubricants. These new lubricants do need protection from excessive mill oil to keep them biodegradable.

7.6.3 Lubrication for Total Productive Maintenance

The present day roll forming line is a highly productive process usually achieved by integrating various operations such as prepunching, postpunching, welding, cutoff, and even assembly on a continuous basis.

This higher level of productivity has to be protected through the implementation of a "total productive maintenance program" (TPM). In this scenario, the players are the company management, production personnel, and the maintenance department, along with key suppliers of roll forming expertise.

A lubrication program for total productive maintenance should cover both process and equipment lubricants. There are three distinct areas of activity that should be implemented and continued on an on going basis to successfully achieve a TPM. They are:

1. Preventive maintenance
2. Database
3. Predictive maintenance.

All of the above areas are equally important. The key points in each sector are discussed below and we show how lubrication expertise can help develop a smooth running roll forming operation.

7.6.3.1 Preventive Maintenance

In planning maintenance, the first area to approach is preventive maintenance of the troublesome lubrication incidents that continue to plague the roll forming operation. The most common problem areas pertaining to lubrication of roll forming are:

1. Dirty coolant tanks
2. Rusted shafts and rolls
3. Leaky gear boxes
4. Worn out drive chains and gears
5. Rusted beds, plates, and pins
6. Problems with automatic lubricators
7. Hydraulic systems

7.6.3.1.1 Dirty Coolant Tanks

The coolant tank could be the largest single source of waste generation in the plant. There are two alternatives — switch to a "lost lubricant" application approach or learn to control the coolant reservoir to minimize waste.

7.6.3.1.2 Roller Shaft Bearings

The roller shaft bearings must be lubricated with a compatible, quality grease that will resist wash out from water solubles and chemical solutions. When chemical solutions (synthetics) are used, then grease must resist the detergency and cleansing action of these alkaline roll forming lubricants. The frequency of greasing is very important. The time intervals should be recommended by the lubricant supplier. The selected grease must have the proper physical and chemical properties to provide sufficient load carrying protection for the bearings.

The frequency of greasing then becomes the time interval for the database needed in predictive maintenance. When ordering new roll forming equipment (or upgrading present system), it is a good time to consider using an automatic lubrication system for roller shaft bearings.

7.6.3.1.3 Shafts and Rolls

Another area that sometimes can be a lubrication headache is the lubrication of shafts and rolls. Too often, the roll forming tooling can be "frozen" to the shaft in a short period of time. Here again, the proper selection of a protective precoat (a rust preventive grease or polymer) is very important. First all shafts, rolls, and tooling must be precoated prior to assembly with the selected lubricant. Selection of the right time to relubricate again can made by selecting test spots or sample areas to be covered with the precoat material. This sample area should be inspected daily, usually toward the end of the shift, for signs of wash off and rust. If this daily inspection routine is not followed, then tooling may be frozen to the shaft in a short period of time. As in the case of roller shaft bearings, the preassembly compound must be compatible with the coolant being used in the roll forming.

The determined time interval for relubrication of shafts and rolls should be recorded in the database.

7.6.3.1.4 Rusted Shaft and Rolls

This problem occurs because of neglect, misunderstanding, and lack of communication. First, make sure that the parting compound selected can withstand the washout from the coolant being used in the roll former. Follow the steps in the predictive maintenance procedure on shaft and rolls to make sure your database provides the proper lubrication intervals for these components.

7.6.3.1.5 Gear Housing

Enclosed gear housings should be treated like a hydraulic system. It should be kept clean and put on a regular maintenance schedule.

On a new roll forming line, the gear lubricant should be changed after the first 250 hr of operation. When filling a gear housing, use the proper viscosity of gear lubricant, remembering that too light a lubricant will mist and oxide more readily. On the other hand, too heavy a lubricant will not splash properly and will not fill the bearing holes properly.

When changing gear lubricant, inspect for uneven or accelerated wear. Broken gear teeth may indicate overloading. Keys that are worn or shredded may also indicate overloading. Accelerated wear may be a consequence of too light a lubricant or dirty lubricant.

The operating temperature should be frequently checked, because excessive heat can cause accelerated wear. If too hot, it is recommended to install cooling coils or a heat exchanger.

Another maintenance idea is to install magnets — the type that can be easily serviced. Magnets should not be installed in the drain plug.

On leaky gear boxes, specially formulated lubricants with leak retardant properties can be helpful.

The physical and chemical properties of gear housing lubricants should be placed on 1000- or 2000-h checks. The laboratory report should indicate the following:

1. Acid number
2. Viscosity
3. Contamination level
4. Moisture presence

Change the lubricant when the analysis indicates this is necessary. On gear and pinion enclosed gear housings, the lubricant is usually an extreme pressure type in the range of (1000 to 2000 s.u.s. (Saybolt Universal Seconds)).

Always clean the gear case after each lubrication change. It is advisable to add a detergent dispersant to the old lubricant before changing for a complete clean out.

7.6.3.1.6 Worn Drive Chains, Sprockets, and Gears

All of these components must be lubricated, depending on the use of the equipment and type of lubricant used. This is generally determined by the lubricant supplier and the customer. The lubrication intervals can vary from daily to weekly. These components are generally neglected, resulting in erratic operation, drive and timing chain problems, and loss of power. Lubricant should not be excessive, but should be resistant to wash off by the roll forming lubricant.

7.6.3.1.7 Open Gear Lubrication

Before lubricating any open gear, make the gear clean and dry and not "oily". An oily film will prevent any of the residual film-type gear lubricants from adhering properly to the gear teeth. Most residual film-open gear lubricants leave a clean, dry film, which reduces the chance for dirt accumulation.

Open gears can be easily lubricated with a cartridge that will fit a caulking gun for easier application of lubricant. It is a good policy to touch-up the open gears when necessary. Do not overgrease. The excess will only slide off. To expedite greasing and inspection of gears, make a small opening in the gear housing cover.

It is also not a good policy to try and use heavy open gear oil on open gears. It can drip off and go into the reservoir that supplies the gibs and ways. Another problem is that heavy open gear lube can get into the main reservoir and plug the automatic lubricator lines.

7.6.3.1.8 Rusty Beds, Mounting Plates, and Guide Pins

These areas must be protected from rusting and corrosion, achieved primarily by the coolant used. Proper coolant selection, maintenance, and concentration are essential. Rusted conditions can lead to tooling problems misalignment of quick-change tooling, ling degradation, and a host of roll forming problems. Cleaning and flushing the bed areas with clean roll forming coolant straight from the tank is a precautionary measure that should be always be implemented. If the roll former is to be idle for weekends, holidays or shutdowns, then spray the belts, roll, plates and pin with a water displacing rust preventive.

7.6.3.1.9 Air Line Lubricators

The air line lubricator in the plant is sometimes taken for granted as not being important. When air line lubricators are not functioning properly, air feeds work erratically. Clutches can wear rapidly. These are costly situations.

A good place to start is to make sure the air line lubricator is connected properly (per OSHA requirements in USA). When operating an air feed, the lubricator should be checked at least twice per week to make sure it is clean, has sufficient lubricant and is operative. On clutch operations, checking once a week is sufficient. Any seals or "O" rings used in the air line lubricator should be compatible with the lubricant. Excessive drying and swelling of noncompatible "O" rings can be harmful.

Installing automatic drains on filter bowls can be quite helpful, especially in areas not readily accessible to maintenance personnel.

Last but not least, if the air supply has high humidity, then the air line should be checked daily and proper maintenance followed on the shop air compressor.

7.6.3.1.10 Air Compressors

The air compressor is an integral part of the plant. Air feeds, air cylinders, automatic lubricators, air line lubricators, clutch diaphragms, and so on, all rely on good-quality shop air. Production just comes to a grinding halt without a properly functioning air compressor.

There are two main types of air compressors used in most shop operations — screw compressors and reciprocating compressors. Most newer installations now use screw compressors. This type of compressor needs high quality lubricant. Many manufacturers' specifications call for a synthetic type compressor lubricant. When petroleum-based lubricants are used, they are generally of the high VI premium type. Good maintenance practice on screw compressors is to drain the condensate from the crankcase daily. A sample of oil should be taken and investigated for unusual characteristics. The oil level should be maintained at all times. It is recommended to set up a lubricant analysis schedule, and the oil should only be changed when the tests indicate this is necessary.

Reciprocating compressors come in many different types of designs, including vertical, horizontal, and some have top cylinder lubricators. In any case, only the proper grade of recommended lubricant should be used in the top cylinder lubricator to maintain the proper feed rate in the lubricator.

The crankcase lubricant is usually a heavier grade of petroleum-based lubricant on reciprocating air compressors. Proper oil level in the crankcase should be maintained and oil conditions should be checked every 30 days. A regular analysis schedule is also advisable for the crankcase lubricant. Some operators change their compressors on an hourly basis (500, 1000 hr, etc.).

Another good maintenance convention is keeping gauge readings on your compressor under normal conditions. A typical air-cooled screw compressor may have an oil temperature of 175°F (80°C). The sump pressure reads 110 psi. The line pressure reading is 106 psi (note that the differential in pressure when the differential reaches 10 to 20 psi usually means the separator needs changing). The oil and filters, including the air intake filters, should be checked every 30 days as noted earlier.

If the temperature of the oil is higher than 80 to 90°C (175 to 195°F) under normal operating conditions, then the radiator usually requires attention and needs cleaning.

7.6.3.1.11 Problems with Automatic Lubricators

Contamination of the lubricant used in automatic lubricators is a common problem.

Contamination can be caused by several factors. Dirty lubricant not being properly filtered or stored can cause lines to plug. Filters and strainers become ineffective and bearing failure may occur. Keep the lubricant clean and change filters and strainers on the recommended basis for the particular type of lubricator.

Monitors should be installed to indicate the reservoir is empty and set to shut off the equipment to avoid running on an empty reservoir. Monitors can also be installed to indicate plugged lines or filters.

Pinched lines and damaged components lead to problems. Lines should be inspected regularly. This includes all hoses, fittings, seals, connections and seals, and looking for any indications of "weeping."

Failure of controls and pumps is hard to determine. The instruction manuals provide hints for pumps such as frequency of replacing seals, packaging, or any special lubrication points that might be involved, and so on.

A ten point check list for maintaining automatic lubricators (grease of oil) is shown in Table 7.3.

7.6.3.1.12 Hydraulic Systems

On flying hydraulic cutoffs and prenotch lines, the hydraulic reservoir should use the proper viscosity of hydraulic fluid designated by the pump or system manufacturers.

All fresh fluid should be pumped in by use of an auxiliary filtering pump (10 μm if possible). Fluid contamination levels should be checked every 6 months by the fluid supplier. Filters should be changed as recommended by the machinery manufacturer. Heat exchangers should be cleaned periodically to maintain a safe operating temperature for the hydraulic fluid of 40 to 50°C (100 to 120°F).

TABLE 7.3 Typical Check List for Automatic Lubricator

1	Clean reservoir periodically (do not use cotton or fiber rags)
2	Inspect suction filter and screens, replace filter at least annually and clean screens
3	Remove strainer and clean regularly
4	Change line filter (pressure filter annually)
5	Check flexible hoses for cracks and wear
6	Inspect tubing/pipe for breaks or flattening
7	Check all connections for “weeping” check tightness of connection but avoid over tightening
8	Monitor system pressure for unusual drops or increases in operating pressure
9	Use only recommended lubricants (be cautious about using lubricants with additives that could clog filters or flow proportioning devices)
10	Follow recommended lubricant storage and filling procedures to avoid introducing air and contaminants into system

7.6.3.1.13 Preventive Maintenance Lubrication Hints

Before a maintenance program is implemented:

1. Make sure all lubricant containers are stored in a clean, safe designated area.
2. Do not store drain oil or used or spent lubricant of any kind with fresh clean machine lubricants.
3. Always pump lubricants through a filter before adding to reservoirs or to gear housing. This should be mandatory for hydraulic systems — a 10 μm filter pump is sufficient.
4. Always flush any system completely and clean thoroughly after any breakdown on hydraulic pumps, gear housings, and so on. Using a detergent dispersant can be very helpful.
5. Follow the lubrication guidelines for the equipment. Automatic lubricators should be filled with the proper grade and type of lubricant. Change lubricants at recommended intervals unless laboratory analysis indicates otherwise, then set up a predictive maintenance procedure for the specific area or equipment.

7.6.3.2 Maintenance Database

To achieve successful predictive maintenance, a database has to be established for the major lubrication areas in the roll forming operation. A typical list of topics that should be covered in the database would include the following:

1. Frequency of greasing roller shaft bearings
2. Lubrication of shafts and rolls
3. Lubrication for drain chains and gears
4. Coolant tank and reservoirs
5. Gear housing lubrication
6. Air line lubrication
7. Air compressors

Lubricant suppliers can help in setting up the lubrication schedule best suited for the equipment.

There are many different types of computerized charts available today that are ideal for database generation. Whatever charts or records systems are selected, they must be kept up-to-date and the necessary action taken by the respective shop personnel involved.

7.6.3.2.1 Coolant Tanks and Reservoirs

Proper design and maintenance of the coolant reservoir is essential for an efficient operation.

After of all the preparation, it is almost mandatory that the coolant reservoir be placed on a predictive maintenance schedule. Lubricant suppliers can recommend analytical equipment necessary to check coolant concentration levels, alkalinity, bacteria content, foreign particles, etc. Generally, titration checks and alkalinity levels can be performed on site with the help of a refractometer or a fluid tester and a pH meter. Foreign particle levels and bacteria are usually performed by the lubricant supplier in their laboratory. In any case, this information should be recorded on the database and adhered to in the predictive maintenance program.

7.6.3.3 Predictive Maintenance Lubrication Hints

Maintenance hints after a program is in place:

1. Keep records of all lubricants used, including initial fills, dates of major breakdown, major repairs, and actions taken, such as cleaning, modifications, and so on. This will be the maintenance database.
2. Have the lubricant supplier set up the necessary time intervals for laboratory checks and analysis on all recirculating systems. The plant environment may determine how often these tests are performed (speeds, operating conditions, temperature, etc.).
3. Record laboratory results into the database, and determine what maintenance procedures or changes are needed for continued operation on hydraulic systems, gear housings, coolant tanks, and air compressors.
4. Understand where all the filters are located on the equipment (this includes automatic lubricators). Learn what time interval is best suited for the equipment, taking into consideration plant environment. This would include hydraulic systems, automatic lubricators, gear housing, recirculating systems, and so on. Keep records on filter changes, oil changes, cleaning, component repair or replacement.
5. Compatible Machine Lubricants: the machine lubricants must resist washout from coolants.
6. Contaminants found in lubricant analysis are helpful in determining troublesome areas in process, such as:
    - Over loading of gear reducers
    - Dirty air breathers
    - Worn seals and “O” rings
    - Dirty reservoirs
    - Contaminated coolant tanks

7.7 Operating Problems during Production

There are four common areas of problems that seem to occur during the roll forming production process including: white rust generation on galvanized materials after forming, “metal pick-up” on rolls, accelerated tool wear, and not understanding the lubrication requirements for secondary operations.

7.7.1 Accelerated Tool Wear

In most instances, accelerated tool wear does not occur in roll forming unless:

1. The lubricant is improperly applied
2. Large amounts of metal fines are generated and not controlled
3. Wrong tooling material is selected for the type of roll forming being performed
4. The tools are incorrectly designed
5. The surface speed different in tooling
6. Rolls are incorrectly set up

When roll forming aluminum or aluminized steel, it’s advisable to wipe off or flush the large amounts of metal fines in order to prevent accelerated tool wear (more about this under roll buildup).

When using chrome plated rolls, and a lubricant is necessary to help reduce friction and heat, it is very helpful to use lubricants with excellent polarity and wetting to insure proper adherence to the chrome tooling surface. Extreme pressure-type water solubles of both the petroleum and synthetic variety may lend themselves well to this type of tooling. When forming painted or coated stock with chrome rolls, a dry, clean lubricating film can be obtained by using an extreme pressure evaporating compound.

When forming over a mandrel, especially on lock seam tubing or close tolerance window sections, make sure you provide positive lubrication to the mandrel in the form of evaporative compound or synthetic soluble.

There are several relatively simple procedures that can be taken to help eliminate lubrication related tool wear problems. Not necessarily listed in order of importance, but certainly helpful, are:

1. Add baffles and magnets to the sump
2. Put filters in the sump
3. Use oil skimmers
4. Reduce excessive greasing or use a grease highly resistant to water wash out
5. Replace worn seals and gaskets on gear boxes
6. Use industrial grade felt wipers (pads), riding on both top and bottom rolls
7. Polish forming rolls when pick-up first appears
8. Add felt wipers to the forming rolls especially when working aluminum
9. Design a closed loop coolant system for easy cleaning, with 10-min recycling coolant capacity, and consisting of the following:
    - One mechanical skimmer
    - Two underflow baffles
    - Magnetic separator or hydrocyclone
    - Regular clean-out schedule

The gains in production, roll life, lower lubrication costs, and reduced rejects will more than offset the maintenance and labor costs of the above suggestions.

Other outside forces and material properties can help contribute to metal pickup. Some of the obvious material problems are stock that is too thick, causing buckling, and jamming of stock in the forming mill. Wedging and sticking of stock in cutoff dies can sometimes be attributed to stock that is oversize.

When material is too wide, excessive wear can occur on the flange areas of rolls. Here again, changes in lubricant properties alone may not be sufficient to solve this type of problem.

Another method of reducing metal pick-up is by using airless type sprayers to mechanically remove the metal fines at strategically located points. Some of the new micromist sprayers can give pin-point control and direction to help remove buildup from critical locations.

Mechanical changes can also be made in the roll forming operation to help eliminate pick-up; changing the peripheral speeds and also the draft on certain forming rolls can be quite helpful.

Because there are so many different precoated materials being roll formed, extra care must be taken to check first with both your lubricant and material supplier before attempting to use any forming lubricant on coated stock. This is especially true not only on galvanized material, but on spray coated, painted, vinyl, paper clad, and electroplated material.

Too often, this prior checking is not performed on coated stocks, and checking, blistering, peeling, blotching, and staining can make the precoated surface become a piece of scrap.

When using evaporative compounds in lubricating painted or coated stock, first, make sure that the evaporative compound is compatible with the surface coating. In most instances, when properly applied, "Aliphatic" solvents do not soften or peel the surface coating. On the other hand, aromatic solvents can definitely soften many material coatings.

7.7.2 "Metal Pickup" on the Rolls (Its Causes and Cures)

The principal cause of metal pick-up on the rolls is the presence of metal particles somewhere in the roll forming operation. These free traveling metal particles can be generated by the very nature of the material being formed, such as galvanized, aluminized, aluminum, and hot rolled. All of these materials generate metal particles when worked. From a material standpoint, these surfaces must be viewed as particle generating surfaces.

Another source of metal pick-up is the slitting burrs that always exist on slit material. These burrs are almost invisible, but they can be felt when touched by fingertips. As the material is formed, these burrs or metal fines break off and float through with the coolant that is lubricating the forming rolls.

Another contaminating ingredient to "roll pick-up" can be the leakage of gear lubricant from the gear boxes, and grease from excessive greasing of the roll stand bearing. This combination of gear lubricant and grease results in the metal fines being trapped in the tramp oil, consisting of gear lube, grease and sometimes mill oil. This whole mess then floats on top of the coolant reservoir, and portions of this contaminated coolant are then pumped and flooded back over the rolls. This contaminated lubricant then is trapped between the rolls and the piece part, causing buildup to accumulate on the rolls. The roll buildup then brings about another problem — marking on the material — which then might be rejected, especially when working commercial bright stock used for appliance trim.

Once lubricants are chosen, some static tests for surface compatibility, cleaning, painting, welding, and plant storage — especially if long-term storage is involved, should be performed. In the case of unusual environmental conditions in the plant, such as high humidity, cleaning vapors for either alkaline, or vapor degreasers, these factors also deserve special attention. All of these variables should be brought to the attention of the lubricant suppliers.

Another consideration is the source of water. Many roll forming lubricants have to be mixed with water, so type and source of water is another variable that should be checked. The stability of your water-soluble lubricant can be adversely affected by water that does not form a stable emulsion with the chosen lubricant. Poor or unstable emulsions cannot lubricate properly in roll forming. Some typical problems incurred by using unstable water-soluble lubricants are rust, spotting, rancidity, and of course, the white rust condition we discussed earlier on galvanized (zinc) surfaces. Your lubricant supplier can adjust certain water-soluble lubricants for maximum stability and rust protection. However, the physical properties of the water being used have to be available so that the proper adjustments can be made. Therefore, a sample of the water to be used should be checked.

7.7.3 Hard-to-Lubricate Surfaces

Sometimes, the surface finish on the material to be roll formed will not retain lubricant properly. This can apply to brightly polished materials, tin plate, and new types of bimetals. Another culprit can be the mill oil itself. Certain coatings may keep water solubles or evaporating compounds from working properly.

Forming of certain steel can sometimes be tricky, especially when a bright or high finished stainless is being roll formed. The surface of most stainless does not retain lubricant as readily as other metals. For this reason soluble with superwet characteristics have been formulated for roll forming stainless. Heavy-duty evaporating compounds containing extreme pressure agents and good antiwipe properties are also effective.

On appliance trim felt wipers may have to be used to remove any spotting from either chemical solutions or evaporative compounds. These bright surfaces will show any residual deposits from lubricants used. These very light films may have to be removed by wipers before the sections are packed and wrapped.

It is essential that roll formed sections and tube be drained of as much coolant as possible. Weep holes should be pierced or drilled in blind sections wherever feasible. Storage should be in selected areas where free circulation of air is not a problem in order to avoid stagnation of any residual fluid. Conditions of high relative humidity (above 70 to 75% relative humidity) aggravate the condition.

When the metal surface temperature drops in the presence of high humidity, the condensed moisture on the section is rich in oxygen because the thin water film is exposed to a large volume of air. Conditions are then ideal foe extensive uniform corrosion.

Zinc is rapidly attacked in acidic and alkaline aqueous conditions. Storage and manufacture within the vicinity of fumes from plating or pickling shops will accelerate metal surface breakdown.

The accumulation of metal fines in a coolant reservoir is another source of potential problems. Should the particulate contaminants not be filtered out or removed, there will be a constant deposition on the metal as it is formed. The particles of fines will create isolated areas of chemical and electrochemical corrosion. Zinc is sacrificial to steel (iron).

7.7.4 Coated Stock

Each coating system has a different reaction to specific roll forming lubricant properties. For this reason, it is imperative that a static compatibility test be conducted on your stock with the type of roll forming lubricant you intend to use (synthetic solution, water soluble, evaporative compound, etc.).

7.7.5 Bimetals

Bimetals are finding increasing use because they are lower in cost and weight of roll formed piece parts. It is like having the best of both worlds; the base metal can be cold roll, galvanized and so on, while the outside skin or cosmetic layer may be of stainless steel or bright aluminum. Always choose a roll forming lubricant that will protect the outside appearance to prevent scratches or scoring.

7.7.6 Long-Term Storage of Formed Products

Once a piece part or component has been roll formed, it may have to be protected for long-term storage either inside or outside.

There are several different methods that can be considered for long-term protection. If a synthetic or water-soluble forming lubricant is being used, a water displacing, rust preventive can be sprayed on when the part is leaving the roll former.

7.7.7 White Rust

There are three specific areas of interest that can contribute to the generation of white rust on electrogalvanized and galvanized material. They are:

1. Condition of purchased material
2. Operating condition during the roll forming process
3. Lubricant properties and lubricant control

Let us discuss each segment of this troublesome problem in turn.

7.7.7.1 Condition of Purchased Material

It is not unusual to have a “white rust” condition on the galvanized stock before the roll forming actually begins. For example, frequently, the galvanized stock is not protected properly prior to delivery to the plant. The material may have been subject to rainstorms, high humidity, salt spray from snow melting, or harsh environmental conditions prior to delivery. All purchased material should be checked carefully prior to fabrication.

Storing of galvanized material in the plant should be checked carefully to make sure the material is properly protected against the plant environment. Material should never be stored near open doors, or near cleaning and plating tanks. Precautions should be taken to protect the galvanized coils or sheets against high humidity, especially the snap condensation that can occur over weekends, vacation periods and holiday shutdowns, and from water flowing from wet or snow covered trucks.

7.7.7.2 Operating and Product Storage Conditions

The following operating conditions give rise to “white rust” generation on roll formed galvanized sections.

Any metal corrosion may be aptly described as the chemical or electrochemical attack by atmospheric moisture or other substances hostile to its surface.

"White rust" is the destruction of the surface of galvanized steel or zinc by oxygen or other chemical elements. The reaction is accelerated by the presence of moisture acting as a catalyst.

The zinc coating may be applied by hot dip galvanizing or electrodeposition and is primarily intended to serve as a protective layer for the main metal substrate.

However, this protective film has its own limitations when subjected to environments antagonistic to its protection properties. The rate of attack is related to temperature, ph and composition of moisture and the concentration of dissolved gases within that moisture. The higher the oxygen and carbon dioxide content, and the softer the water, the greater the rate of surface breakdown is. When the water is present, the corrosion cycle starts with the formation of zinc oxide, which, in turn, is converted to zinc hydroxide and then to basic zinc carbonate in the presence of carbon dioxide. The final product prevents the onset of further corrosion at that particular area of attack providing no highly acidic or alkaline contaminant becomes involved later.

Under enclosed conditions such as blind angles and box sections, rapid attack by the available oxygen gives rise to a pitting condition as the exhausted gas is not replaced as fast as it is used. The corrosion pattern, therefore, is nonuniform and typical of "white rust" conditions.

It is essential that roll formed sections and tubes be drained of as much coolant as possible. Weep holes should be pierced or drilled in blind sections whenever feasible. Storage should be in selected areas where free circulation of air is not a problem in order to avoid stagnation of any residual fluid.

Zinc is rapidly attacked in acidic and alkaline aqueous conditions. Storage and manufacture within the vicinity of fumes from plating or pickling shops will accelerate metal surface breakdown.

The accumulation of metal fines in a coolant reservoir is another source of potential problems. Should the particulate contaminants not be filtered out or removed, there will be a constant deposition on the metal as it is formed. The particles of fines will create isolated areas of chemical and electrochemical corrosion. Zinc is sacrificial to steel (iron).

The chemical and physical properties of the lubricant may contribute to "white rust." Some of these properties are unstable water-soluble materials, active chemical agents such as chlorine or sulfur (which are not properly inhibits). In general, stable emulsions of properly selected synthetic solubles are best for galvanized surfaces. Evaporative compounds can work well on these surfaces also.

Another precaution that should be taken in lubricating galvanized material is to prevent excessive amounts of water-based lubricant from being allowed to remain on roll formed sections. This trapped water can definitely contribute to a "white rust" condition, especially when parts are nested or stacked.

Some operators will blow off the excessive water-soluble lubricant before the cutoff in order to minimize the amount of residual left on the part. As noted above, stacking parts so that the configuration provides for air circulation is extremely helpful.

Conditions of high relative humidity above 70 to 75% aggravate corrosion. When the metal surface temperature drops in the presence of high humidity, the condensed moisture on the section is rich in oxygen because the thin water film is exposed to a large volume of air. Conditions are then ideal for extensive uniform corrosion. Closely packed, tightly nested, products stored outside the plant cool down during the night. During the day, the large amount of water condenses on the surface of the cold metal.

Because there are so many different precoated materials being roll formed, extra care must be taken to check first with both your lubricant and material supplier before attempting to use any forming lubricant on coated stock. This is especially true not only on galvanized material but on spray coated, painted, vinyl, paper clad, and electroplated material.

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8

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8.1 Flow of Material

As a result of the high productivity of roll forming lines, large quantities of material are received, processed through, and shipped out of the manufacturing plants. At many plants, the operators and material handling personnel spend more time with handling material than with producing goods.

The handling and storing of the material is concentrated in the following areas:

1. Incoming material receiving, unloading, inspecting, and marking
2. Material (coil or sheet) storage
3. Moving coils (or occasionally bundles of sheets) to the processing line
4. Passing material through the line
5. Removal of roll formed products from the line
6. Stacking, bundling, marking, and packaging products
7. Storage of roll formed products
8. Transporting finished products to the next operating station or shipping them out of the plant.

The selection of equipment and accessories for incoming material handling depends on local conditions and should be assessed separately in each instance. The following conditions may influence the selection:

- In-plant or outdoor receiving
- Available building and layout of plant
- Method of transportation used for incoming material (trucks: open bed or van; railway cars: open beds or box cars)
- Floor- or depressed-level receiving area
- Quantity of material received per day and per year
- Orientation of coils (center line, or “eye” of the coil horizontal or vertical) when received and stored
- Requirements to weigh coils
- Method of coil storage
- Method of loading coils onto roll forming line
- Availability of in-line coil storage
- Amount of equipment to be serviced
- Special requirements (e.g., sensitivity of the material to handling or environment)
- Available funds.

Primary metal manufacturers, coil coaters, or service centers usually deliver the wider, hot rolled, cold rolled, galvanized, or sometimes prepainted steel coils with their axes in horizontal position. Narrow coils, most prepainted steel coils, aluminum, and other metals are shipped with vertical axes (“eye in the sky”) on pallets.

Unless specific instruction are given to the supplier, the direction of coil axes will be determined by the convenience of handling, loading, and shipping, and by the sensitivity of the material to the horizontal and vertical accelerations and decelerations during transportation.

At most plants, the cranes, forklift trucks, and other material handling equipment have additional functions to loading and unloading the roll forming line. They are also used to unload incoming trucks, load material for storage, remove finished products from the line, and load them on to trucks.

It can be a frustrating experience to operate the line efficiently at high speed, and then stop and wait for 20 to 30 min for a crane or forklift truck to load the next coil or to move the completed product. For efficient operation, it is important to reduce the unproductive “down time” of the lines. Therefore, it is advisable to make the line as self-sufficient and independent from the plant material handling equipment as possible. Entry end and in-line coil storage and handling devices, as well as exit end product handling and in-line temporary storage facilities, can keep the roll forming lines running for hours.

8.2 Coil Handling and Storage

8.2.1 Receiving Coils

With the exception of a few sheet-fed lines, coils are the starting form for roll formed products. Most of the time, coils are shipped to the manufacturing plants on open bed trucks. Closed trucks and railway cars are seldom used for transportation.

Incoming material is sometimes unloaded from the transport vehicle outside the plant by crane or forklift truck. However, it is preferable to move the material into storage or to the roll forming line with the same equipment in one handling.

Inside plant unloading is most common because it reduces coil handling time and minimizes the effect of weather. Open bed trucks or railway cars inside the plant can be unloaded with crane or with forklift trucks. Closed vans and the very seldom used box cars stationed at the dock level are unloaded with low mast forklift trucks.

Coils should be visually inspected for damage, marked, entered into the inventory, and then moved into the storage area. Checking weight, thickness, camber, waviness, surface appearance, and mechanical properties may be a part of the receiving procedure.

8.2.2 Coil Storage

The selection of coil storage method and the coil storage area layout has a long lasting influence on product cost. Incorrect storage method and layout can be expensive, either because of unnecessary investment or the time wasted by searching for, moving, and accidentally damaging coils for many years or decades.

Coils with either horizontal or vertical axes can be stored in storage racks or in multiple heights on the floor.

8.2.3 Storage Racks

The primary steel manufacturers and steel centers, frequently store coils in racks (see Figure 8.1). Racks provide easy access to any coil and minimize the damage to them. Coil loading and removal can be automated, using stacker cranes. However, storage racks are expensive and corridors between the racks occupy considerable floor space. Usually, roll forming plants can neither afford nor fully utilize storage racks.

8.2.4 Storing Coils with Horizontal Axis on the Floor

This is the most inexpensive and effective way to store coils. It is applicable to hot and cold rolled, galvanized, or frequently to prepainted steel. Wide, 10-ton coils can be stacked 4 to 5 high as shown in

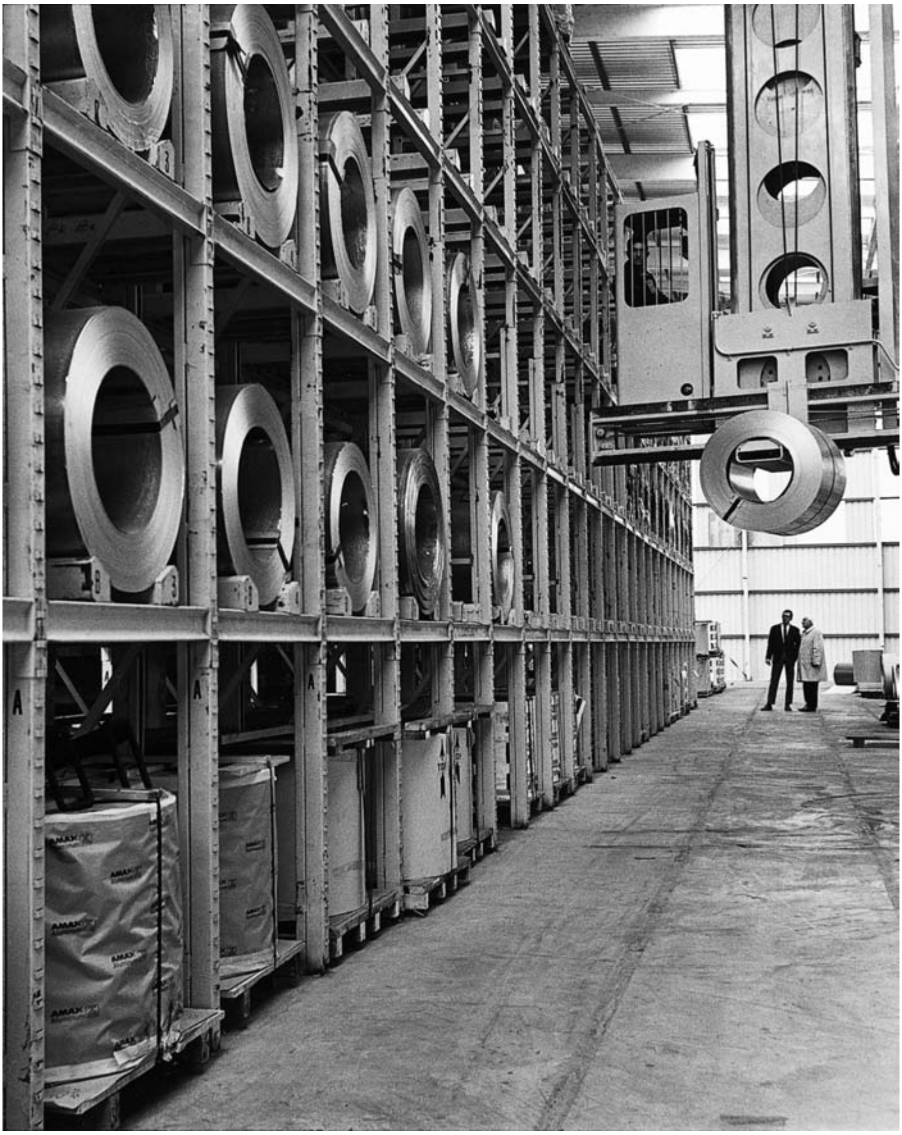


FIGURE 8.1 Coil storage rack loaded with stacker crane. (Courtesy of Palmer Shile Company.)

Figure 8.2 if the strength of the plant floor and the height of the crane hook permits it. Depending on soil conditions, about 8 to 10-in. (200 to 250-mm) thick, reinforced concrete floor is usually sufficient for coil storage.

To prevent the sideways rolling and collapse of the coil "pyramid," sufficient support should be provided to the two outside (end) coils at each bottom row (see Figure 8.3).

Coil storage on floor is a "dense" arrangement, and storage area is effectively utilized. However, more time is required to "search" for coils in "mixed coil rows." The chance of damage to the coils is also higher and this method is not well suited to store of leftover coils with only a few inches of wraps. However, in most places, this is still the most economic method of storing coils with horizontal axis.

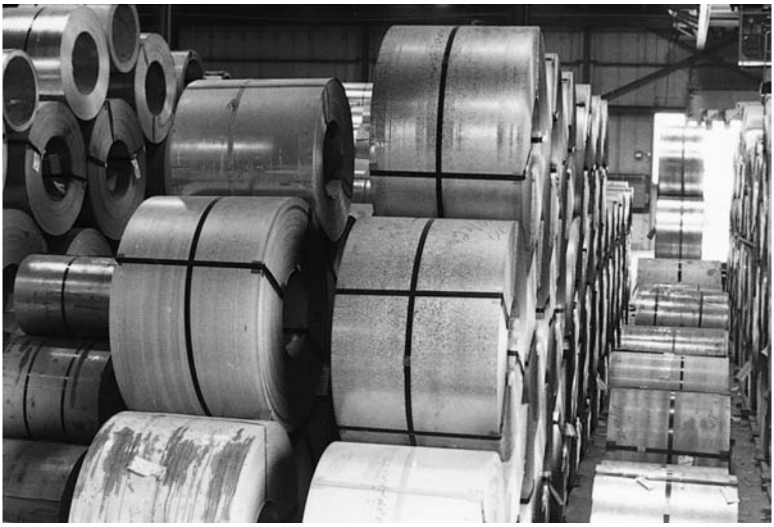


FIGURE 8.2 Storing coils on the floor.

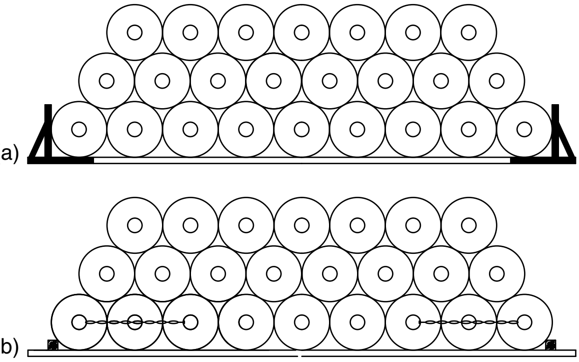


FIGURE 8.3 Coil stops (a) or chains (b) prevent the "rolling-out" of the end coils.

8.2.5 Storing Coils with Vertical Axis on the Floor

Coils fastened to pallets, as shown in Figure 8.4, are frequently stored in multiple heights. Advantages and disadvantages of this method are similar to those pertaining to the method mentioned above, but storage space utilization is less effective than storing coils with horizontal axis.

Narrow coils, strapped to pallets or skids, are usually stored in this way at most roll forming plants. Narrow coils, stored with vertical axes ("eye in the sky") for safe handling, are "flipped" over when they are placed on the uncoilers.

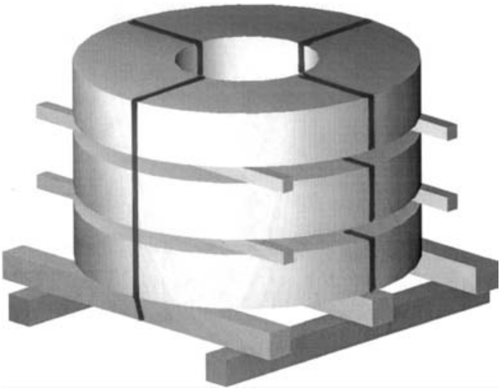


FIGURE 8.4 Storing coils with "eye in the sky."

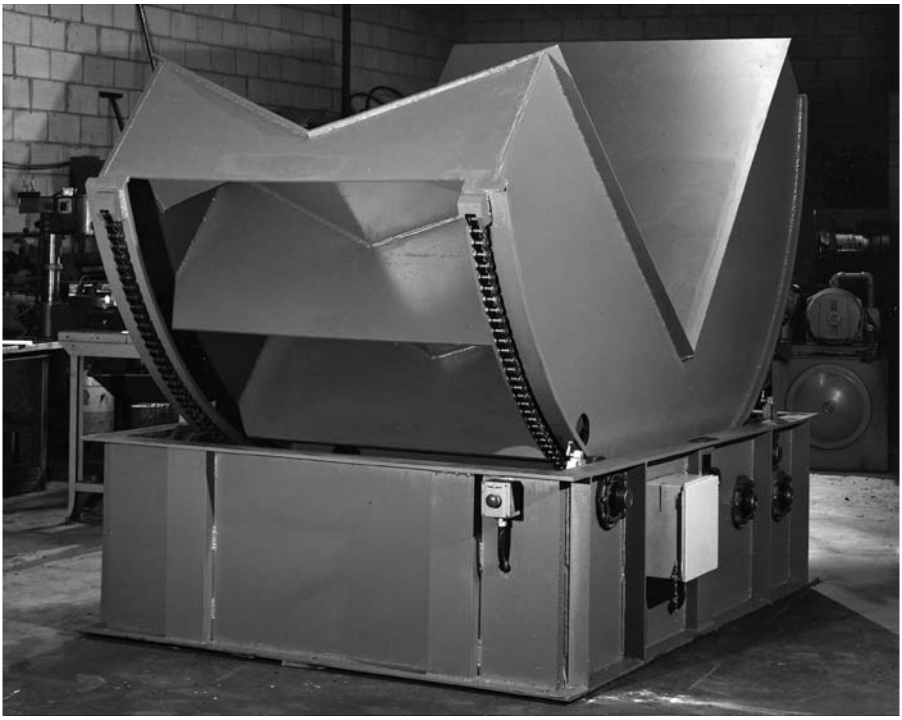


FIGURE 8.5 Coil upender. (Courtesy of Bradbury Co. Inc.)

Wide coils shipped with horizontal axes are stored and loaded onto the uncoilers in the same position. Wide coils received with vertical axes (eye in the sky) can be stored in this position or with their axes rotated 90°, usually with an upender, to the horizontal position before placing on the line. Alternatively, they can be "upended" before placing in the storage area. Local conditions will determine the more effective procedure with the least handling time and travel distance.

8.2.6 Coil Upender

All uncoilers and reels, except the pallet decoilers and the continuous coil stacks, are loaded with coils having horizontal axis, while either all or frequently a large portion of coils are shipped to the plants with vertical axes. In most cases, the vertical axis is rotated to horizontal one with an upender (see Figure 8.5) and the coils are loaded/unloaded by forklift trucks or cranes.

To install an upender for each line would be too expensive; therefore, most plants have one upender only. All incoming coils with vertical axes must be placed on the upender, either when received or when moved to the roll forming equipment. The extra trip to the upender increases the traveling distance of each coil, but the handling time increases even more drastically. Palletized coils with vertical axes must be unloaded with fork attachment while handling of coils with horizontal axes is preferred with "C" hooks or coil grabs. To comply with this requirement, the crane attachments are changed after each upending.

8.3 Sheet Handling and Storage

Only a small percentage of the material processed through the roll forming lines are in sheet form. Sheets received on skids or in bundles are handled by trucks, sheet grabs or with another crane attachments using forks. In most cases, sheets are stored on the floor, in multiple bundle heights.

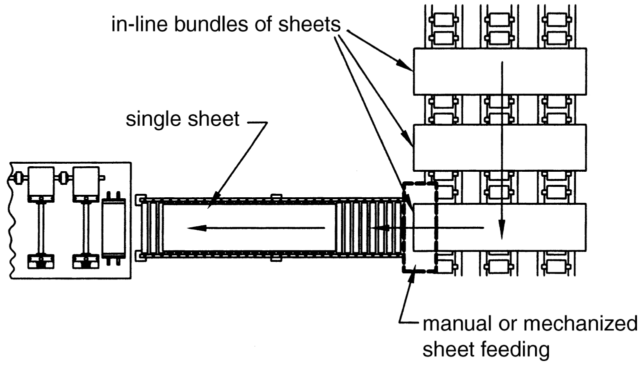


FIGURE 8.6 In-line bundle storage eliminates crane/forklift truck waiting time.

8.3.1 Placing Bundles into Feeding Position

Bundles of sheets or prepierced, notched blanks are usually placed into the feeding position by material handling equipment (crane, truck etc.). Production delay caused by waiting for handling equipment can be eliminated by loading several bundles side by side on a roller or chain conveyor. When the last sheet of a bundle is removed, the next bundle can be moved into the feeding position by a chain conveyors or pushers (Figure 8.6).

Bundles are occasionally moved into position by trolleys, or several bundles are placed on top of each other on a lifting table. The table can automatically lift the top sheet of the bundle into the right feeding height.

8.3.2 Separating and Grabbing Sheets

Moving a sheet usually causes fewer problems than separating it from the next sheet in the bundle. Trying to grab a single sheet on the top of a bundle can be cumbersome for the operator wearing protective gloves. Oily sheets may create a vacuum effect, "sticking" the sheets together. Rust or grease can make the separation even more difficult.

The simplest method of separating or "fanning" steel and certain stainless steel sheets is to use simple, permanent magnets (Figure 8.7). The edge of the separated top sheet can be easily grabbed and moved.

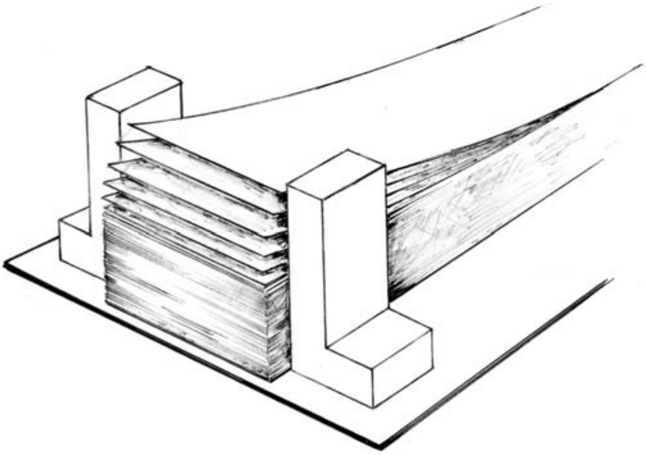


FIGURE 8.7 "Fanning" magnets separate top sheets of the bundle.

In the case of long sheets, a quick up and down shaking movement by the operator creates a wave throughout the length of the "light gauge" sheet. Air entering into the wave separates the rest of the top sheet from the next one and makes it easy to slide forward.

Suction cups attached to the operator's hand, glove or to a handle are frequently sufficient to "grab" and pull the top sheet.

Mechanized sheet-feeders can be expensive, but they are efficient. They are frequently used to feed precut sheets to eliminate one or more operators at the entry end of the line.

Lifting and holding of the top sheet is usually performed by vacuum cups. Occasionally, lifting magnets are used. In both cases, especially with magnets, lifting of two or more sheets at a time should be prevented.

The previously mentioned fanning magnets can be helpful in the case of mechanized feeders. If the top sheet is pulled sideways or forward, instead of lifted, then a fan can be applied to blow air between the separated sheets. The air creates an "air bearing" type of flotation and the separated sheets can be easily moved.

The sheets are sometimes advanced in the longitudinal direction. However, it is usually simpler to lift and move them sideways (Figure 8.8). However, if sheets can be fed into feed (pinch) rollers, then a short forward movement is sufficient (Figure 8.9).

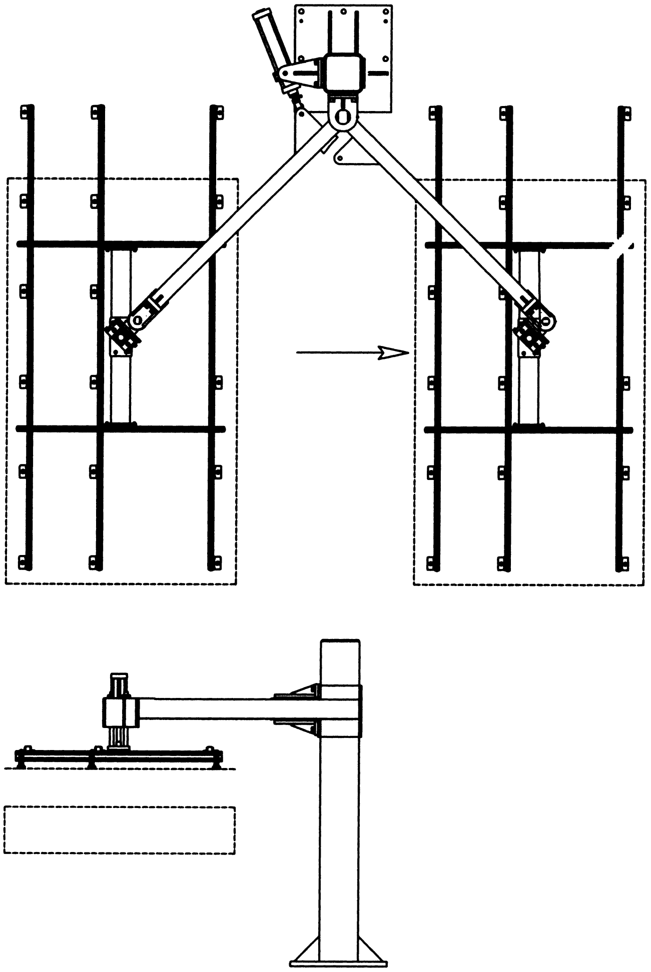


FIGURE 8.8 Vacuum cup lifting device moving sheets sideway. (Courtesy of CompuRoll Inc.).

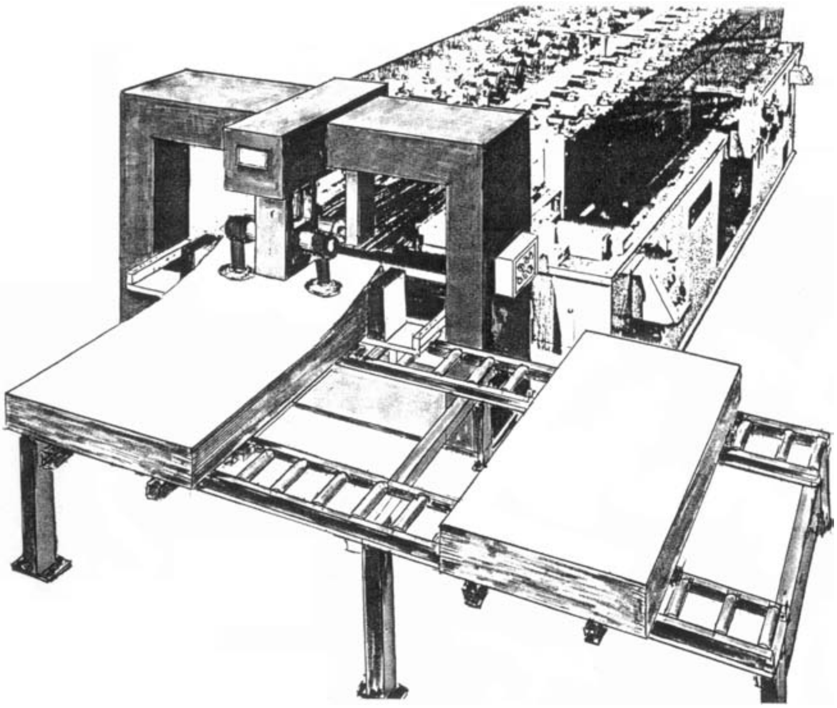


FIGURE 8.9 Feeding unit (conveyor table, sheet height sensor, magnetic fanner, vacuum pick-up and feed mechanism, pinch rolls). A conceptual drawing.

8.4 In-Line Coil Handling

8.4.1 Purpose of In-Line Coil Storage

Waiting for a crane or truck is often the cause of reduced productivity. In-line coil (sheet) storage and handling equipment can eliminate the waiting time almost completely, and make the line independent from material handling equipment for 0.5 to 4 hr.

In-line coil storage can have a capacity of 1 to 10 coils or more, depending on the method and the coil widths. Good in-line facilities can increase the output of fast lines by as much as 20 to 30% or more.

8.4.2 Coil Ramp

This device was one of the first “in-line” coil storage equipment. It consists of a slanted surface on which the wide coils “roll down” by gravity, in one direction (see Figure 8.10). The coils are held in position by the individually operated hydraulic stops. Lowering the stops releases the coil, which rolls down to the next stop and finally on to a coil car.

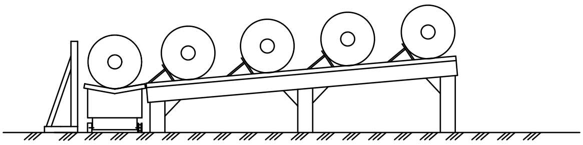


FIGURE 8.10 Coil storage ramp.

The advantages of the system are its low price. The disadvantages are numerous; its safety is questionable, as it is not easy to stop a heavy coil rolling downhill. Coils can be only loaded on the uncoiler in the same sequence as they were loaded on the ramp, and the partially used coils, removed from the uncoiler, cannot be placed back on the ramp.

8.4.3 Coil Cradle

The coil cradle is extensively used by the stamping industry. Occasionally, it is applied to feed narrower coils into a roll forming line (Figure 8.11).

8.4.4 Coil Rack

A coil rack is used in lieu of coil ramp. It may consist of two parallel bars on which 2 to 6 coils are resting (Figure 8.12). The coil car travels under the coil and lifts up the one nearest to the uncoiler. Coil racks are safe but they can only be unloaded in the sequence of coils loaded on the rack; unused coils cannot be placed back on the rack and the rack cannot be reloaded with new coils until the last coil is removed, or at least moved forward by the coil car. This coil storage device is frequently used in culvert and some other lines.

8.4.5 Coil Conveyor

A live floor or underfloor conveyor (Figure 8.13) carries the coils forward to the coil car, which lifts up the coil on to the uncoiler. This system is often used by primary steel manufacturers for moving coils in a line, but the coil users seldom install it.

8.4.6 Turnstile

This is a frequently used device with two, three, or four arms to hold coils (as shown in Figure 8.14). It is a flexible device; coils can be taken off at any sequence and partially used coils can be reloaded back on to the arms. The disadvantages of this device are that it requires large amounts of floor space, up to 200 to 400 ft^2 (18 to 36 m^2), and its cost is relatively high. Coils are usually loaded on the arms of the turnstile by cranes and occasionally by forklift trucks. The upper side of the turnstile arms has a cavity wide enough to accept the arms of the coil grab or other lifting device reaching into the core of the coil.

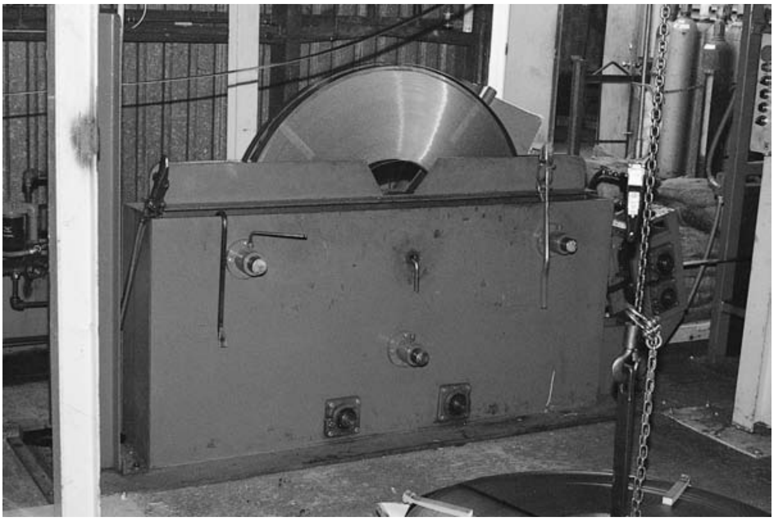


FIGURE 8.11 Coil cradle.

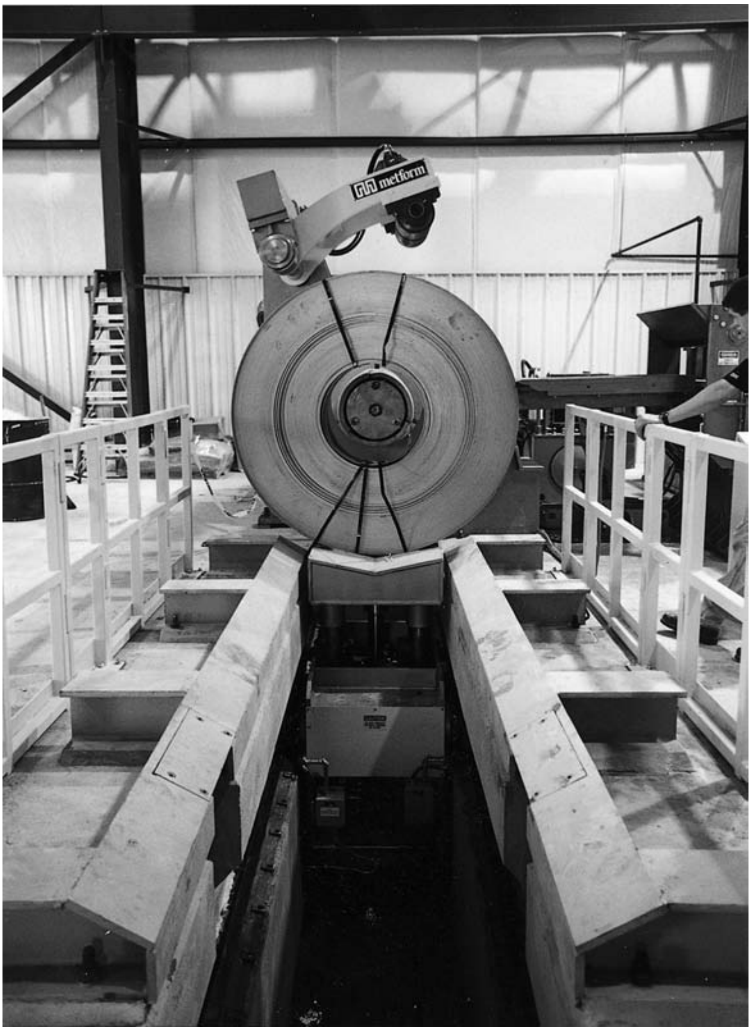


FIGURE 8.12 Coil rack with pit type coil car. (Courtesy of Metform International Ltd.)

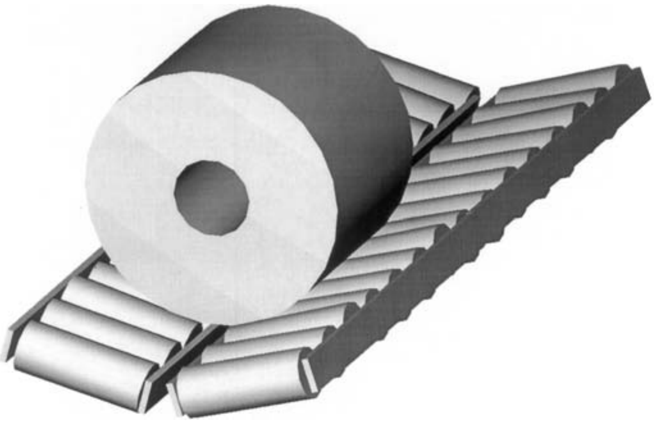


FIGURE 8.13 Driven coil conveyor.

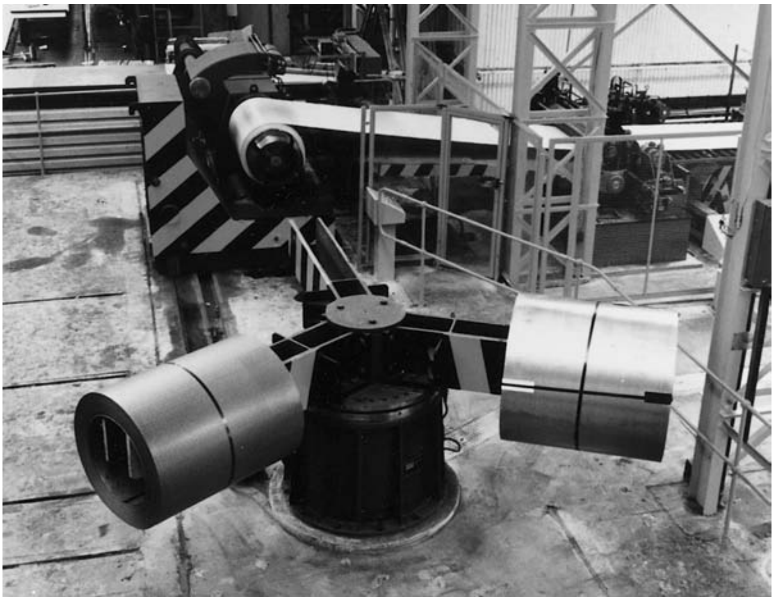


FIGURE 8.14 Turn stile.

Turnstiles are rotated by hydraulic or other power, and a locking mechanism usually ensures the right position of the arms for unloading coils on to the coil car. Rotation speed should be fast enough for efficiency, but safe enough to avoid accidents and damage to the equipment in case of sudden stops.

8.4.7 Coil Car

Coil transporting and lifting cars are the devices most frequently used by the industry to load and unload uncoilers or coil storage devices.

Coil cars either travel above the floor level (Figure 8.15 and Figure 8.16) or in a pit (Figure 8.12). Whenever possible, the floor-level coil car is recommended. Open pits represent safety hazards, and

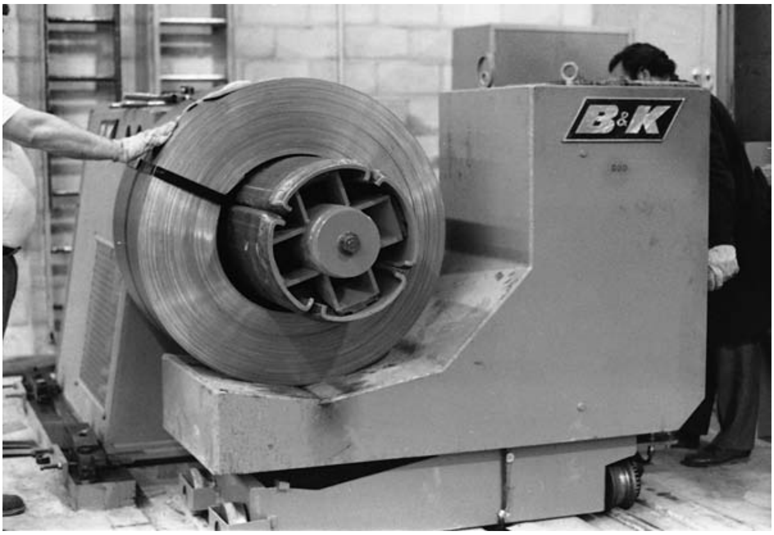


FIGURE 8.15 10-ton floor-level coil car.

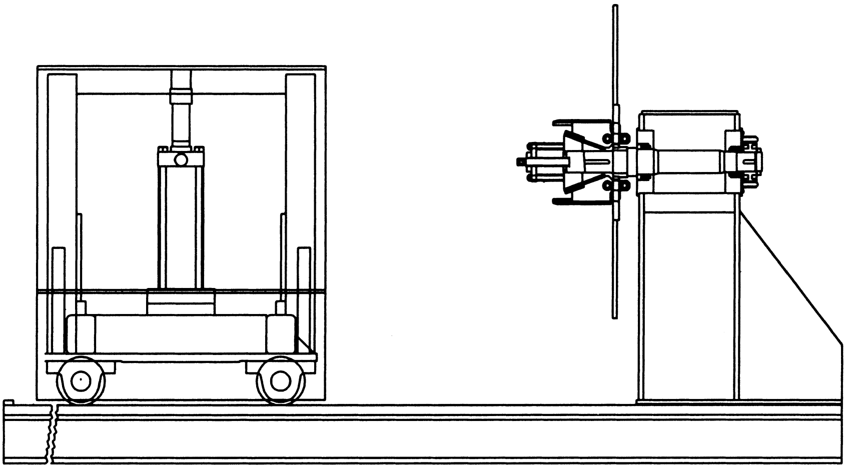


FIGURE 8.16 Coil car, rails, and uncoiler mounted on the same structure.

walking around them every day can waste a considerable amount of time. It is also expensive to relocate coil cars running in a pit.

Most coil cars are travel on rails in a straight line. Rails are relatively inexpensive and guide the coils on to the uncoiler easily. However, protruding rails can be an obstacle to surface traffic; therefore, either the rails should be sunk into the plant floor, or safety walkways should be provided (as shown in Figure 8.17). As an alternative to rails, flat bars or inverted angles can be used for rails for supporting light to medium duty coil cars (Figure 8.18).

Occasionally, coil cars are lifted/lowered mechanically with screw jacks, but most of the time, a hydraulic cylinder is used for lifting. The hydraulic power pack is either built into the car (see Figure 8.19)

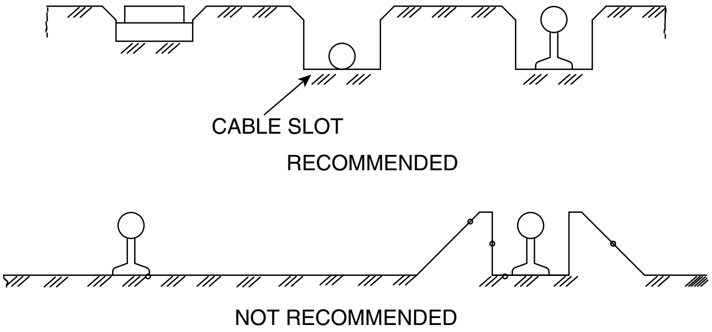


FIGURE 8.17 "Hiding" protruding coil car rails.

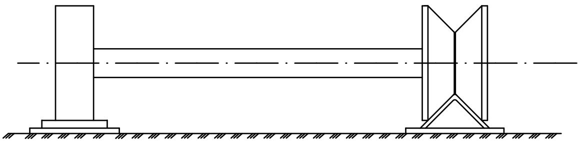


FIGURE 8.18 Inverted angle and flat coil car rails.

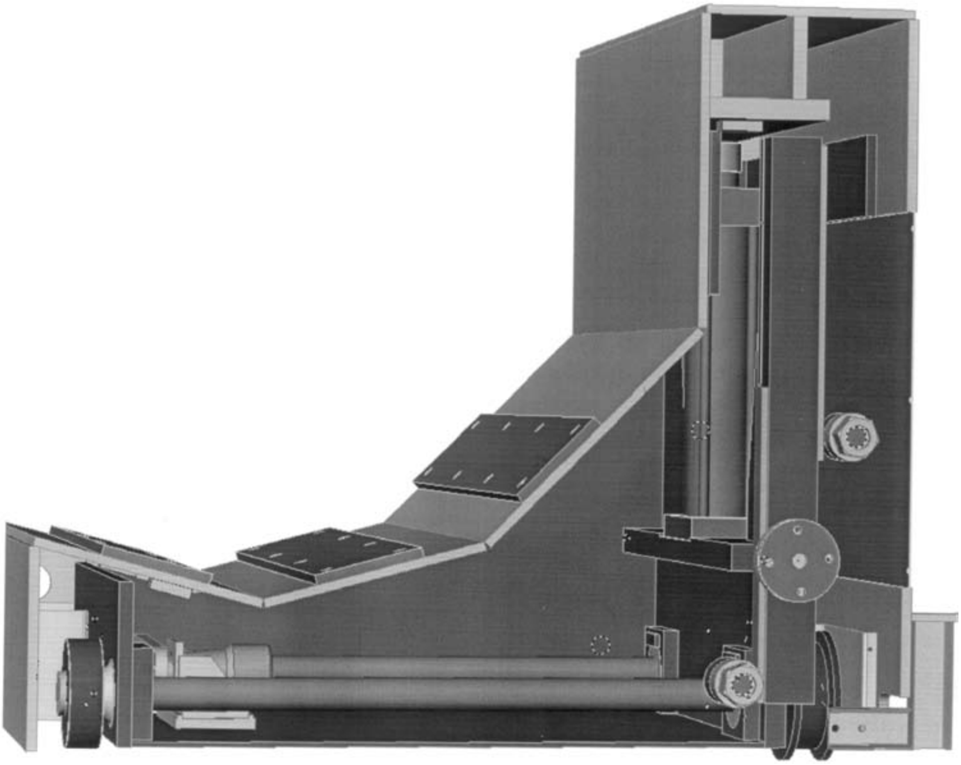


FIGURE 8.19 Coil car with “built-in” hydraulic lifter. (Courtesy of Metform International Ltd.)

or the power pack of the uncoiler is utilized. Hydraulic controls permit easy and accurate control of both vertical lifting and horizontal traveling.

Coil cars occasionally have optional functions such as upending coils or “kickoff” (remove) coils by tilting their tops. A rotary coil car top may be used if the access for forklift trucks is available only at 90° to the axis of the uncoiler.

For better control and safety, it is preferable to have the coil car control right at the coil car. Local controls, such as pendulum type, will allow the operator to “walk” with the coil car and position the coils on the uncoiler accurately and safely.

To reduce initial capital expenditure, one coil car can serve two opposing roll forming lines.

Coil cars not confined to rails, such as hovering air pallets, under floor cable-guided coil cars or coil cars on casters are seldom, if ever, used by the roll forming industry.

8.5 Coil End Welding

Sometimes, it is difficult and time consuming to thread the lead end of the coil through the line, especially through some sweeping, curving, or spiraling tools. Other operations such as in-line seam welding, painting, plastic or rubber extrusion, and other processes demand an uninterrupted flow of product through the critical process. In these cases, the problem can be solved by joining the tail end of the last coil to the lead end of the next coil.

8.5.1 Seldom used Coil End Welding Methods

a. *Gas and oxyacetylene welding* is occasionally used where threading the coil end through the line is complicated. It is inexpensive, and only limited welding skill is required. However, it is slow, unreliable, and the strip weld seam has to be ground to the parent material thickness, often both sides of the strip.

b. *Arc* (*stick electrode*) *welding* is also occasionally used in lieu of gas and oxyacetylene welding. The advantages and disadvantages of this process are similar to those of gas welding and it is not recommended for coil joining.

c. *GMAW* (*gas-metal-arc welding*) or frequently called metal inert gas (MIG) welding can be performed semiautomatically, but the removal of extra weld thickness is still required. Therefore, it is not a practical coil end joining method.

d. *Mash seam welding* is a modified resistance welding process. The ends of the coils are overlapped and current is passed through them through copper electrodes. Its advantage is high speed and good-quality weld, but in some cases, a metal build up of 10 to 15% is undesirable for roll forming. Adequate size equipment can yield a good joint with the same metal thickness as the parent material.

e. *Mash seam welding and planishing* is an improved butt welding. The high force applied to the rotary electrodes reduces the weld thickness to the parent material thickness. It is relatively fast and provides good weld, but it is seldom justified for roll forming operations.

f. *Submerged arc, plasma, laser or other weldings* are usually not used for coil end welding unless special conditions such as thickness or type of material or other requirements make it necessary.

8.5.2 Recommended Coil End Joining Methods

8.5.2.1 GTAW (Gas-Tungsten-Arc Welding)

GTAW, frequently called tungsten inert gas (TIG), welding is the most practical and most frequently used coil end joining method. Semiautomatic welding provides repeatedly uniform quality welds. Once the welding unit is set, any operator can use it. Therefore, no previous welding knowledge or welder classification is required to operate the welding unit.

The ends of both coils have to be properly positioned in order to produce good welds. To ensure good alignment of the coil ends, a shear is usually incorporated into the coil end welding unit. At first, the tail end of the last coil is sheared and then positioned in a weld clamp. Then, the leading end of the next coil is sheared, its end butted to the end of the previous coil and both ends are clamped. The last step is to automatically weld the seam and unclamp the strip.

To minimize the impact on the rolls by the changed material thickness at the weld, the strip ends are sheared and welded at 10° to 20° off the perpendicular position (skewed).

In the case of semiautomatic welders, the shearing and clamping is accomplished manually. In the automatic welder, only a push button has to be used to complete the cycle

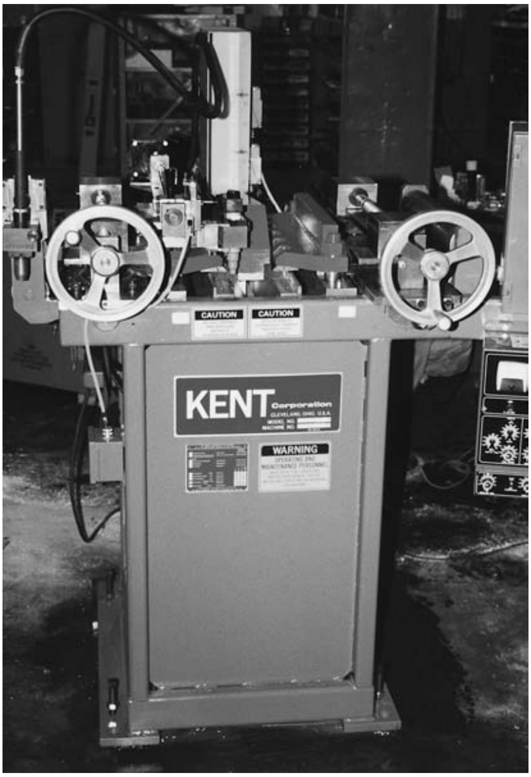


FIGURE 8.20 Coil end shear and welder. (Courtesy of Kent Corporation.)

automatically. The complete cycle takes about 1 to 3 min, depending on the type of welding machine, material type, thickness, and strip width. The advantages of the GTAW welding are that no excess material has to be removed, the operation is reliable and fast, and it is applicable to almost all roll formed material. A self-contained unit can be installed to an individual line, or a common coil end welding unit, rolling on casters, can serve several lines.

Thicker and higher strength coiled materials will retain their curved shape after uncoiling, especially at the inner wraps. The ends of these coils have to pass through a three-, five-, or seven-roll (or other type of) strip straightener before clamping them for welding.

GTAW welding provides good strength, but the strength of joint can be below the strength of the parent material. Therefore, the finished part containing the coil end weld may have to be scrapped. In the case of long structural components, where welding is permitted, instead of scrapping the part, additional arc or other welding may be used after roll forming to restore the strength of the finished part.

End welder units (see Figure 8.20) are commercially available.

8.5.2.2 Flash Welding

The flash welding process utilizes an electric arc to heat the strip ends. The ends are brought together under light pressure, current is applied and the ends are pulled slightly apart. The arc between the ends melts the metal, and then the ends are pressed against each other. Excess metal is squeezed out. This method is fast and provides good weld, but it is expensive and the presence of extra material thickness is detrimental to roll forming.

8.5.3 Nonrecommended Coil End Joining Methods

8.5.3.1 Resistance Welding

Resistance welding of overlapped coil ends is simple, but it is not recommended to pass double thicknesses of material through a roll gap designed for a single thickness. Trying to join butted (not overlapped) coil ends is possible but it is time consuming and ineffective.

8.5.3.2 Stitching

Stitching used in some coil processes like painting or galvanizing, is also not practical because of the multiple thicknesses created by the joining process.

8.5.3.3 Taping

Coil ends joined with plastic or other tapes usually do not have the necessary strength, and will increase the overall thickness. However, on rare occasions, it is used for soft, thin materials. Tapes sticking to the rolls can present a problem.

8.6 Strip (Coil) Accumulators

The interruption of some continuous processes such as painting, tube welding, extrusion, generates a large amount of scrap and downtime. Running out of coil material can cause the interruption. The tail end of one coil can be welded to the lead end of the next, new coil, but welding takes 1 to 3 min. To avoid production interruption, the strip can be fed continuously into the mill or another process from a “strip accumulator” while the strip ends are welded together.

Usually the strip accumulator is located after the coil end welder and must store enough material to keep the line running without interruption while the coils ends are welded together. If the complete joining process (from running out of coil to starting to process the coil) takes 2 min, then the storage capacity of the accumulator for a line running at 200 ft/min (80 m/min) should be more than 400 ft (160 m) with an added capacity for safety.

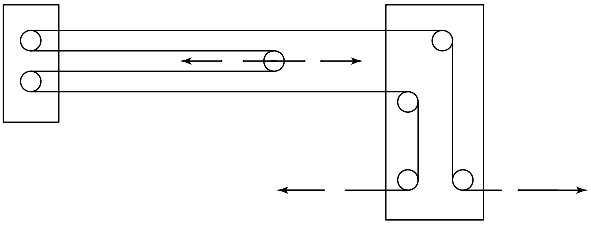


FIGURE 8.21 Horizontal coil accumulator.

8.6.1 Overhead Loop and Vertical Loop

Figure 8.21 shows the common method used until the 1970s to provide material for continuous welding, galvanizing, or painting. These large and expensive accumulators have practically never been used in conjunction with roll forming lines. However, a smaller version of the vertical accumulator shown in Figure 8.22 is utilized to supply narrow strips for roll forming lines running continuously for in-line extrusion.

8.6.2 Horizontal Coil Accumulator

This type of accumulator, sometimes called a "spiral accumulator" (see Figure 8.23), can store strips of considerable length. The strip width can be either to the inner side or to the outside of the accumulator, but in both cases, the strip is turned 90° for feeding and processing. The disadvantages of the horizontal accumulator is the large floor area occupied by the unit and the strip surfaces sliding on each other in the opposite direction.

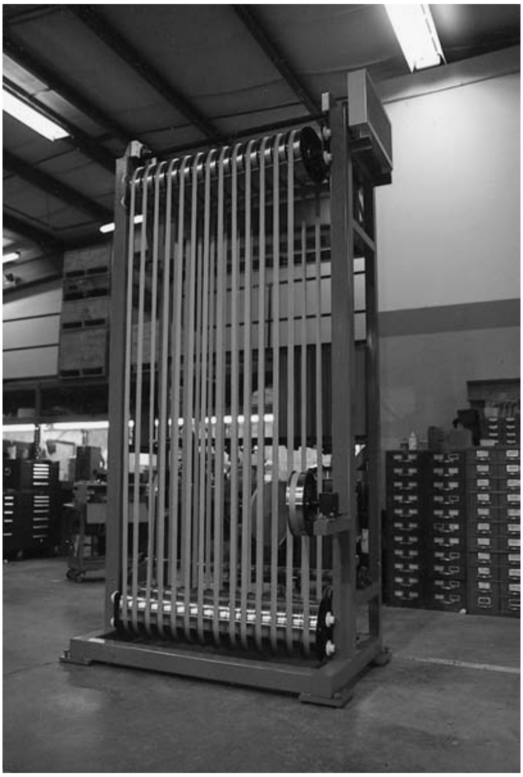


FIGURE 8.22 Vertical coil accumulator. (Courtesy of Kent Corporation.)

8.6.3 Vertical Rotary Accumulator

A vertical rotary accumulator can store large lengths of strip (1000 to 3000 ft or 300 to 900 m). Strip surfaces are not rubbing against each other and it occupies relatively small floor area. The accumulator is shown in Figure 8.24. The vertical coil accumulator is a good device to store narrow strips, but it is not easy to justify the capital expenditure unless continuous flow of material is needed for the operation.

8.6.4 Continuous Coil Stack Feed and Pallet Decoilers

The continuous coil stack feeder is a relatively low-priced method to provide uninterrupted flow of narrow strip. Several coils are placed with spacers between them on a vertical horn. The end of the outer wrap of the lower coil is welded to the inner wrap end on the next upper coil. The outer wrap end of the second coil is then welded to the inner wrap end of the third coil and so on. The complete stack can be prepared outside the line. The stack is positioned in the line on a special uncoiler and the lead end of the top coil is flatted through an indexing and a take-out stand into the roll forming mill.

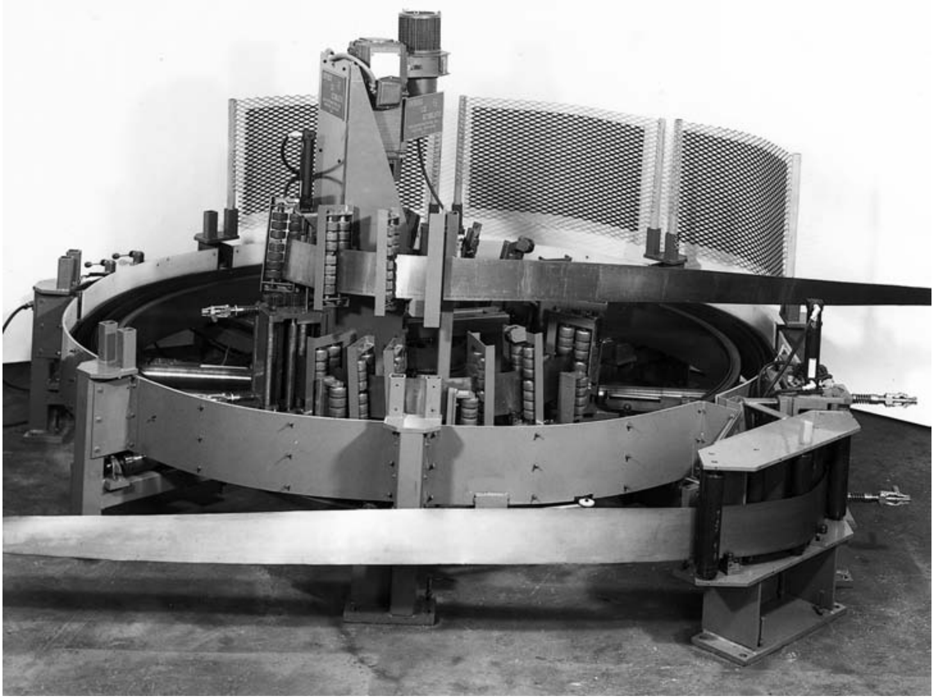


FIGURE 8.23 Horizontal spiral coil accumulator. (Courtesy of Guild International.)

The preparation of the coil stack outside the line is relatively lengthy but it does not interfere with the operation of the line.

Pallet decoilers are similar to the coil stack feeder, but the coil ends are not welded together. The pallet with multiple coils, as received from the supplier is placed on the decoiler (Figure 8.25). After the top coil is depleted, the lead end of the next coil can either be fed directly in the roll forming line or welded to the end of the previous coil.

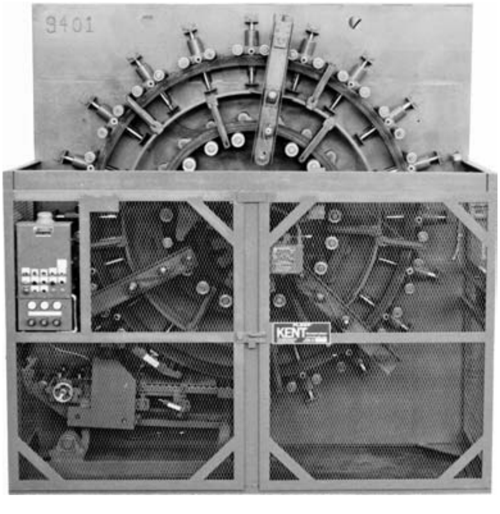


FIGURE 8.24 Vertical spiral coil accumulator. (Floop; Courtesy of Kent Corporation.)

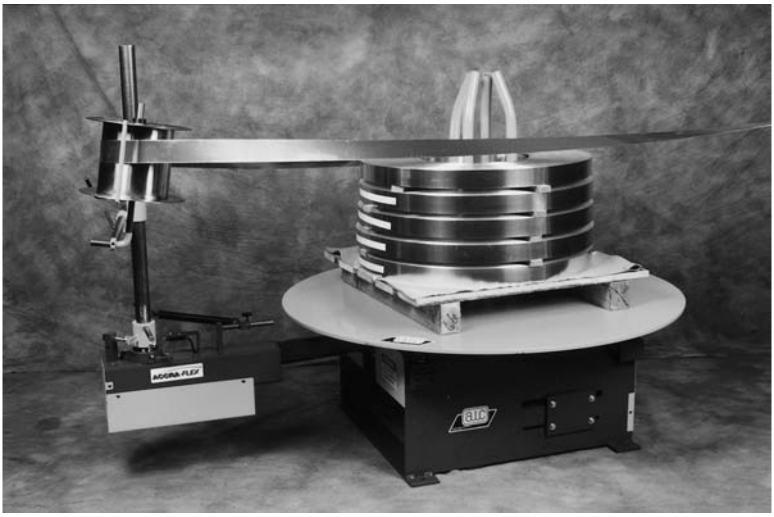


FIGURE 8.25 Pallet decoiler. (Courtesy of Accra Wire Controls, Inc.)

The factors restricting the use of the coil stack and pallet decoiler methods can be the speed of roll forming line, the thickness and strength of material and the coil width.

8.7 Flattening and Leveling

8.7.1 When is a Flattener Required?

Coils always have some degree of deviations from straightness and flatness. The bend lines in the roll formed products frequently are strong enough to minimize or eliminate the effect of the deviation in the strip. For example, coils used for corrugated building, siding, and roofing panels are not required to be flattened before roll forming.

In some other cases, a flattener is highly recommended. For example, the rigidity of the thick and/or high strength material makes it difficult or impossible to feed the strip into the roll forming mill (Figure 8.26), to weld coil ends together (Figure 8.27), or to pass the strip through a prepunching die.

8.7.2 Flattening

In the flattener (Figure 8.28), the material is bent up and down around rolls. The roll diameters are small enough to create a permanent deformation in the material. This controlled permanent deformation will prevail over the permanent deformation in the starting material. Longitudinal bow and coil breaks can

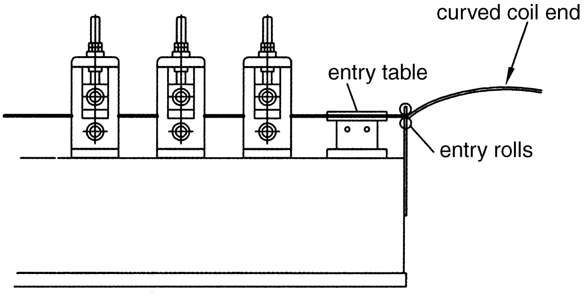


FIGURE 8.26 It is not possible to feed permanently curved “stiff” coils into the roll forming mill without a feed table.

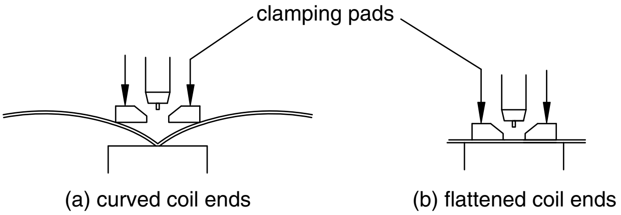


FIGURE 8.27 It is not possible to properly weld permanently curved "stiff" coils.

usually be fully eliminated and crossbow can be eliminated or reduced. However, the flattener will not eliminate edge waviness, center waviness, camber, and some other problems.

Flatteners may have 3 to 11 rolls, but most of the flatteners used in roll forming lines have 5 to 7 rolls. The flatteners are installed after the uncoilers. In the case of thin or narrow material, the strip may be

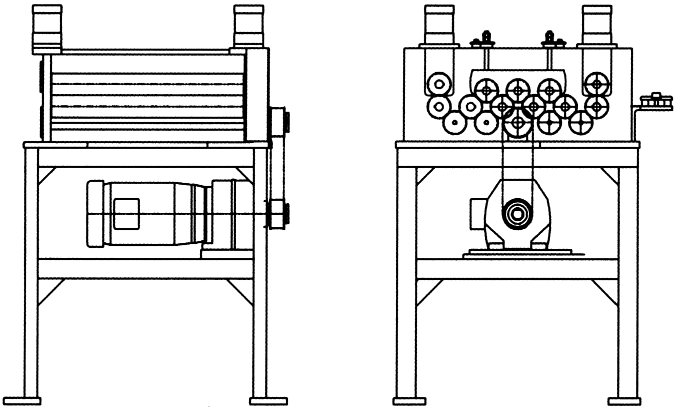


FIGURE 8.28 Flattener. (Courtesy of CompuRoll Inc.)

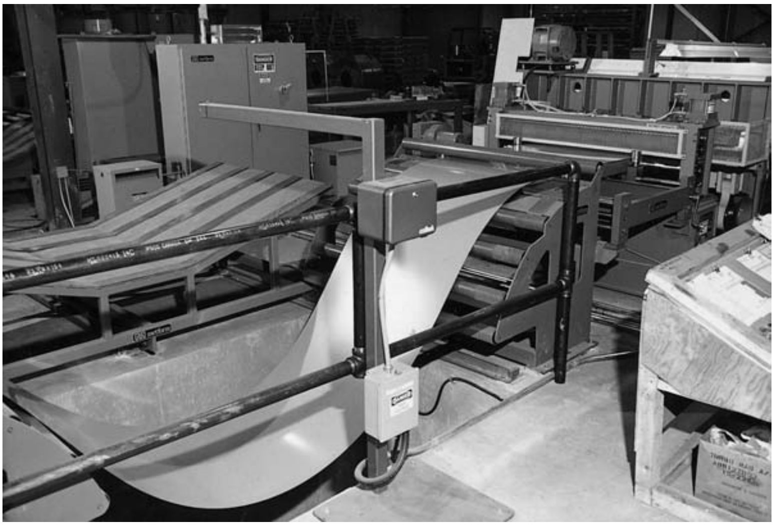


FIGURE 8.29 Pinch rolls can feed strip into a loop before precutting, prepunching, or roll forming. (Courtesy of Metform International Ltd.)

"pulled through" the undriven flattener by the roll forming mill. However, in most cases, the flattener is driven.

The driven flattener usually has one pair of pinch rolls ahead and one pair after the flattening rolls. The pinch rolls can be used to pull the material off the uncoiler and feed the strip into a loop before the precutting shear, prepunching press, or roll former (Figure 8.29).

For a given material such as steel or aluminum, the permanent deformation will be a function of the flattener roll diameter to material thickness ratio. To achieve the permanent deformation (flattening), thin material and relatively small diameter rolls are required. Small diameter rolls can be too weak for thick material. Therefore, depending on its construction, a flattener can be used only for the specified material thickness range.

8.7.3 Levelers and Shape Correctors

Individual (sheet) levelers are similar to flatteners, but they have about 17 to 21 rolls. Levelers can eliminate more imperfections and provide flatter surface than flatteners. However, continuous tension leveling at the mills or steel centers provides sufficient flatness. Therefore, sheet levelers are not used in the roll forming lines.

The wave-free surface, created by tension leveling, is flat because the process balances the internal stresses. If the balance is broken by roll formed bend lines, then waviness may reappear between the bend lines or at the edges. Wide products with several bend lines and narrow flat areas will not show "center waviness" because the larger waves are broken down to sometimes acceptable small waves. However, wavy edges still can create problems. Therefore, for this type of products, "slightly" center wavy coils are often a better starting material.

On the other hand, wide flat panels, which have only the edges formed, can easily display center waviness. Starting coils with flat center and slightly wavy edges may be better for these products.

"Shape correctors" are special flatteners, placed between the uncoiler and the roll forming mill. They can be adjusted to strain (elongate) either the edges or the center of the coil. This flexibility is achieved by adjusting the relatively small diameter rolls with a series of supporting rolls which can either deflect the rolls at the edges or at the center (Figure 8.30). If the ends of these small diameter rolls are deflected "deeper into each other," then the outside edges of the coils can be stretched beyond permanent deformation, and will become wavy. If the center part of the rolls have smaller center distances (deflected more), then it is possible to create "center-wavy coils." With proper adjustment (deflection) of the small diameter rolls, it is possible to produce "flat" coils. Shape correctors can improve the quality of the finished products, but there is no guarantee that "perfect" wave-free product can be made from every coil.

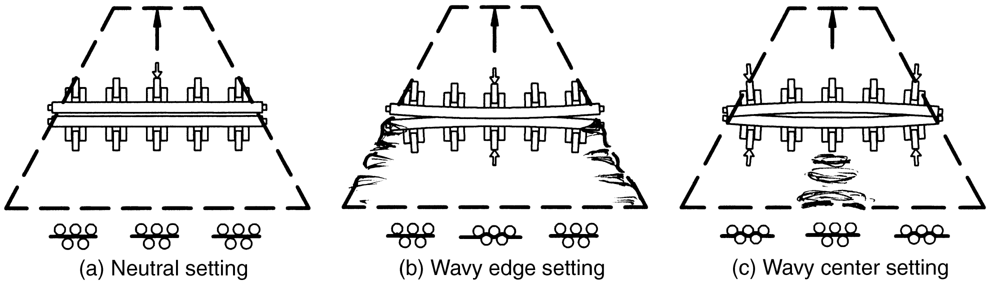

(a) Neutral setting (b) Wavy edge setting (c) Wavy center setting

FIGURE 8.30 Corrective leveler.

8.8 In-Line Sheet Handling

8.8.1 Sheet Grabs

Starting material fed with precut strips or sheets for roll forming lines is usually cut to length in front of the roll forming mill or in a separate operation. If the sheets or strips are prepared on a separate equipment or purchased cut to length, then the prepared bundles are usually stored on skids. The skids or bundles of sheets strapped together can be stored on top of each other. The precut sheet bundles or skids can be handled with sheet grabs suspended on crane hook. They can also be handled by forklift truck. However, carrying long bundles with forklift truck is usually cumbersome and it requires considerable floor space.

Sheet grabs usually can support the bundle in full length. The arms can be adjusted manually or by motor to suit the sheet (strip) width.

8.8.2 Sheet Conveyors

Sheets from the bundles or from the previous operations can be fed into the roll forming line entry guide by hand or by sheet feeders. However, in most cases, the sheets are placed on a conveyor that carries the sheets into the line. Conveyors are also employed between operations and at the end of the line.

The sheet conveyors have to be designed more for abuse than for load. The weight of the sheets is far below the capacity of the properly selected conveyor. Almost all conveyor damage is caused by placing or dropping heavier loads on the conveyor, walking on them, hammering, and other mistreatments.

Conveyors can be either undriven (live) or driven.

8.8.2.1 Ball Conveyors

Ball conveyors, commonly used for heavier plates, are seldom used for linear transportation of sheets. They may be employed when sheets are moved in two directions or rotated (see Figure 8.31). Ball conveyors are not driven; instead, pushers or chain pullers can be used. Rotation can be accomplished by hand, by gravity, or by pushers.

8.8.2.2 Air Flotation Conveyors

Air flotation is achieved by blowing low pressure air through small holes located in a flat table. The air pressure keeps the sheets levitated. This frictionless, "noncontact" support prevents scratches and marks on the surface, but sheets must be flat. The application of the air flotation table is similar to the ball table, and is infrequently used.

8.8.2.3 Roller Conveyors

These are the most commonly used transport units in roll forming.

In most cases, standard steel rollers are suitable to transport sheets. For special applications, plastics or rubber coated steel, aluminum, or plastic rolls are used to protect the material surface.

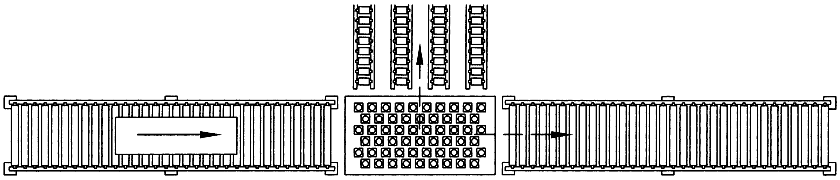


FIGURE 8.31 Ball table can be used for moving sheets in different directions.

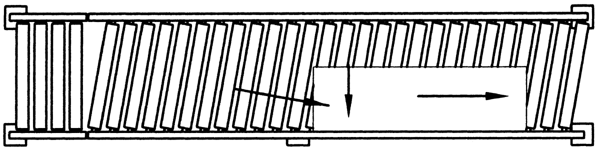


FIGURE 8.32 Skewed conveyor.

8.8.2.4 Undriven (Live) Roller Conveyors

Sheets placed on a conveyor can be moved manually or by gravity, chain, pushers, or by one or more powered rolls or belts located on the top of the sheets.

8.8.2.5 Driven Roller Conveyors

The sheets are moved by powered rotation of the rollers. The rollers can be driven by chains, round plastic belts, or occasionally by a belt underneath the conveyor rollers. Rollers for driven conveyors can be similar to the undriven ones. Sometimes, magnetic rolls are used for a more positive grab of the steel sheet. In special applications, magnetic rolls can be above the sheets, holding and moving them by magnetic force rather than supporting from underneath.

8.8.2.6 Special Roller Conveyors

Conveyor rolls are sometimes "skewed" to achieve a special effect. Skewed rolls drive the sheets not only forward but also to one side, against a guide. This arrangement helps to align randomly placed sheets for the next operation (see Figure 8.32).

Tapered rolls or curved conveyors, frequently used in warehouses for changing the direction of moving boxes or other goods, are seldom used for sheets.

8.8.2.7 Light Duty Conveyors

Light duty conveyors, with plastic or metal rolls mounted on rods, are used to support sheets between operations, between the forming rolls of duplex mills. They are also applied between the mill and cutoff press, at the center of the duplex mills (Figure 8.33a), in front of the edge punching press (Figure 8.33b), or at other places to prevent buckling or bending of the sheets.

8.8.2.8 Belt Conveyors

A large variety of belt conveyors are used by the industry to transport sheets into the roll forming line in between operations, or to remove products at the end of the line. Driven belts can cover the full width of the conveyor or can consist of two or more parallel strips or ropes. The advantage of the belt conveyor over the roller conveyor is its ability to work at an inclined angle, if a change in the working height (pass line) is required. Shorter belt life and higher price are its disadvantages. Belt conveyors are also less practical if sheets have to be rotated or pulled off the belt.

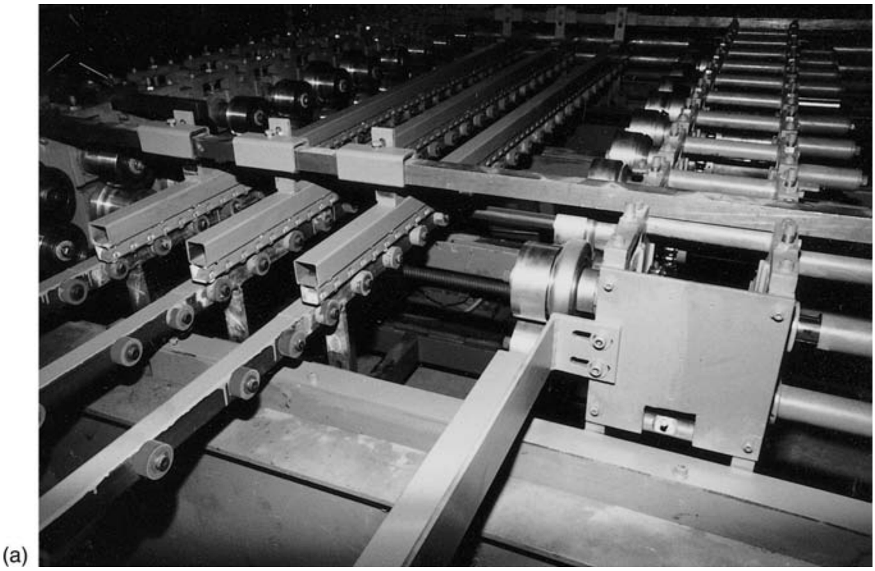
8.9 Finished Product Handling

The starting coil or sheet enters the roll forming line in flat shape. The shapes of the finished products emerging from the other end of the line have limitless variations. Finished products can be removed manually by one or more operators or by mechanical methods.

8.9.1 Handling Individual Product

8.9.1.1 Dropping Finished Products

The simplest method is shown in Figure 8.34; the short pieces drop into a tote box or crate at the end of the line.


(a)

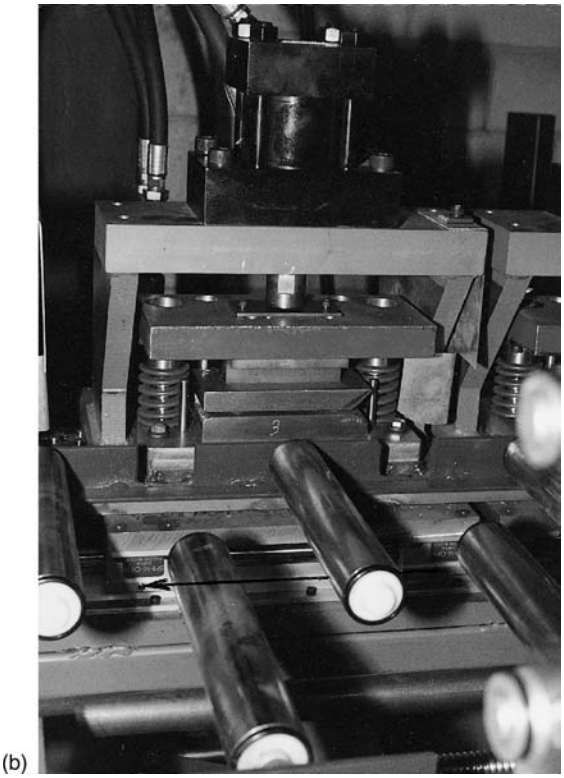

(b)

FIGURE 8.33 Special support conveyors (a) between duplex roll former and (b) at edge punch.

Longer pieces can be moved against a deflector, or pushers from the sides can remove the product from the runout table, as shown in Figure 8.35. The product then slides sideways into a holding container. Roll formed tubular products may roll down sideways from the exit table. If the products are to be packaged in specified numbers, then an operator may stand beside a tilted table. When the required number of

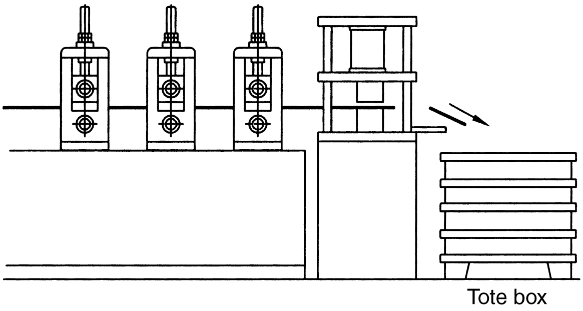


FIGURE 8.34 "Dumping" finished products into the box.

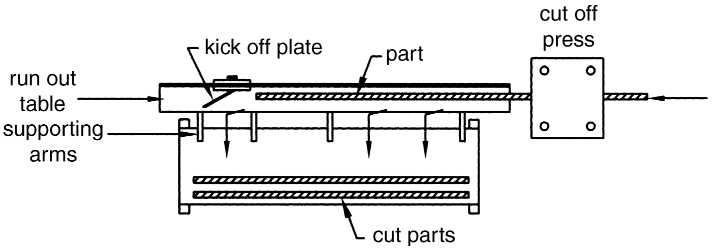


FIGURE 8.35 Parts moved sideways from runout table.

products has exited the mill, they can be moved manually (or mechanically) and bundled or packaged while the next group of products exits the mill.

Heavy products, as well as light ones, can be moved sideways by tilting the runout table (see Figure 8.36).

The drop table shown in Figure 8.37 is frequently used to stack wider building panels when sheets have to be supported along both sides in the runout table. The end of the panels is aligned either at their leading or tailing end, and then the panels are dropped on top of the previous panel. Completed bundles are usually moved sideways from under the drop table by motorized chain conveyors.

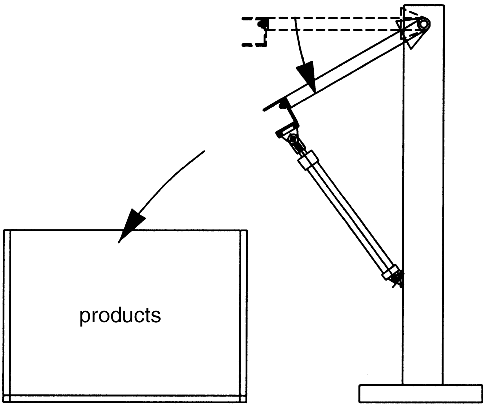


FIGURE 8.36 Tilt table drops products sideways.

If it takes longer to package the products than to produce them, then packaging can be completed at two locations. In this case, the "flip-flop" device located at the center of the runout table will push one product to the left and the next one to the right (Figure 8.38). The "flip-flop" device can also be set to direct a predetermined number of products to the left side operator for packaging, then switching the next lot to the right side operator.

The same "flip-flop" device can also be used to separate the defective products from the good ones.

8.9.1.2 Moving Products After Forming or Cutting

After cutting to length, the product has to be moved forward to separate it from the next piece. They can be moved manually, on top of a live conveyor table, occasionally by gravity, or by powered units (Figure 8.39).

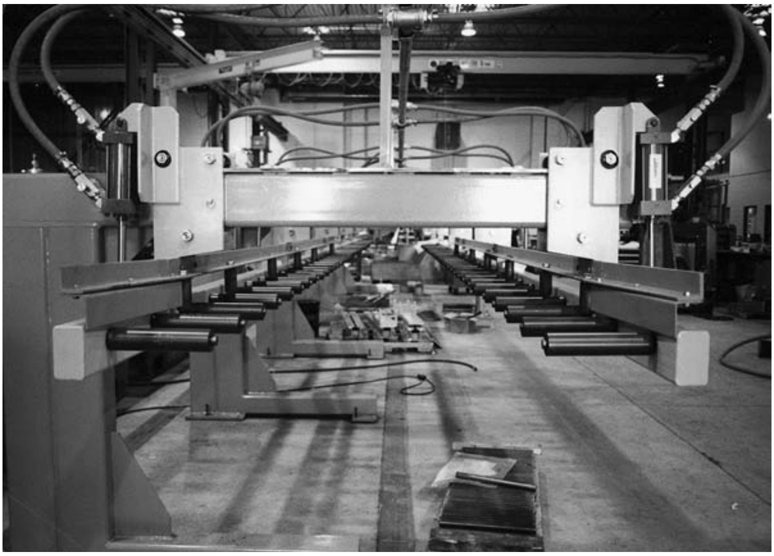


FIGURE 8.37 Drop table for wide, nestable building products. (Courtesy of Metform International Ltd.)

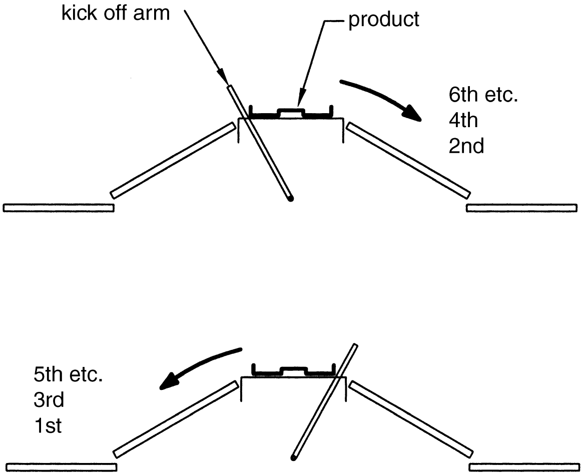


FIGURE 8.38 Flip-flop device can direct products to the right or to the left.

Powered steel roller conveyors with a low friction modulus are the most practical if products are also moved sideways. Conveyor belts or rollers with protective coatings are used because of their higher friction modulus and better surface protection. However, these conveyors are less convenient when products need to be pulled off sideways.

In the case of a nondriven roller conveyor or flat table, the product can be moved either by hand or by a separate motor-driven, rubber- or plastic- (usually urethane) coated roll. The driven roller is usually in contact with the cut products only momentarily in order to "kick-out" the sheets (Figure 8.40). The "kick-out" speed is set 25 to 100% higher than the roll forming speed to create a gap between the just-cut product and the next one. The gap will allow for easier disposal of the product.

Occasionally, products made from steel or certain types of stainless steel with magnetic properties are carried by magnetic rolls (see Figure 8.41). Magnetic rolls prevent slipping when moving the product

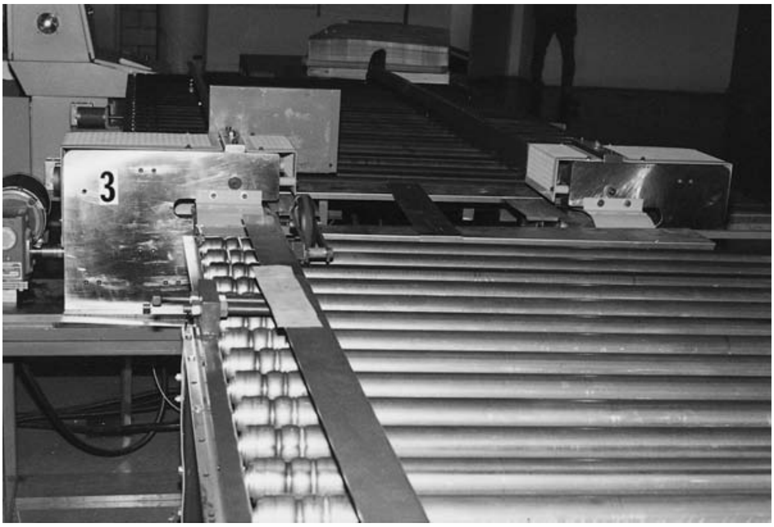


FIGURE 8.39 Powered roller conveyor.

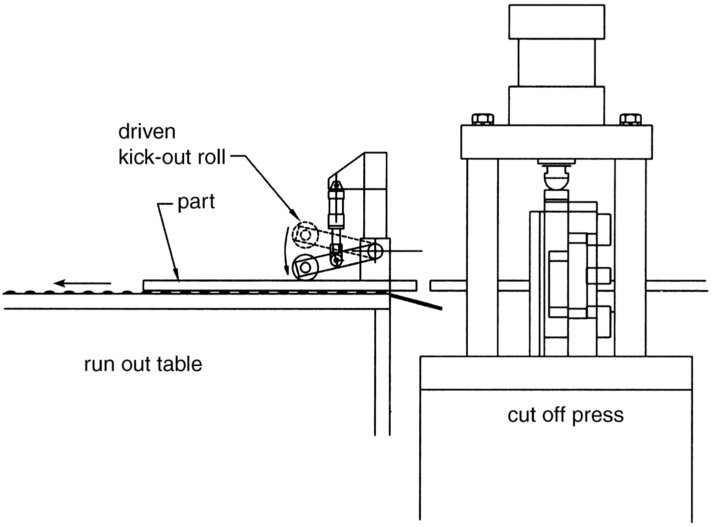


FIGURE 8.40 Powered kick-out unit above a nonpowered roller conveyor table.

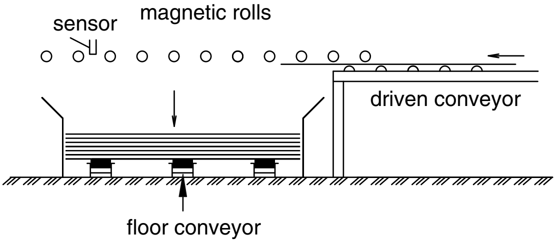


FIGURE 8.41 Products carried by magnetic rolls.

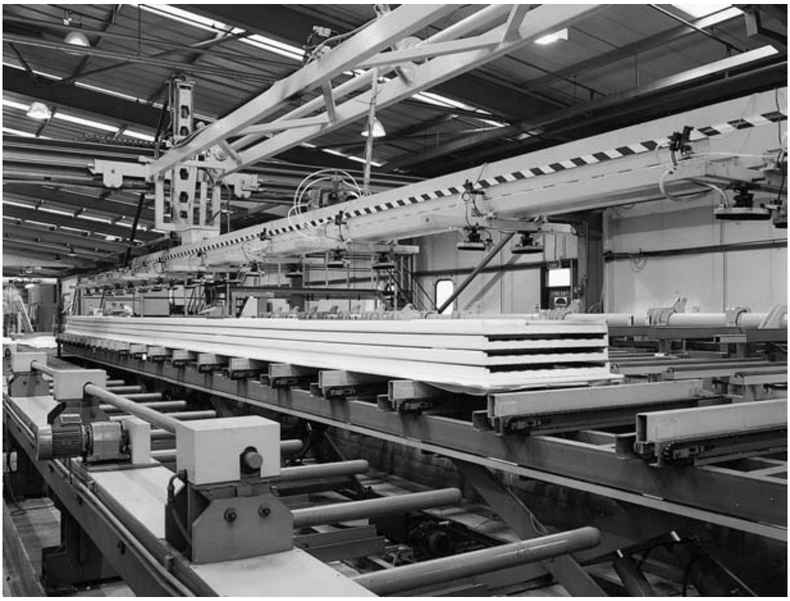


FIGURE 8.42 Foam-filled products picked up and moved with vacuum cups. (Courtesy of Metform International Ltd.)

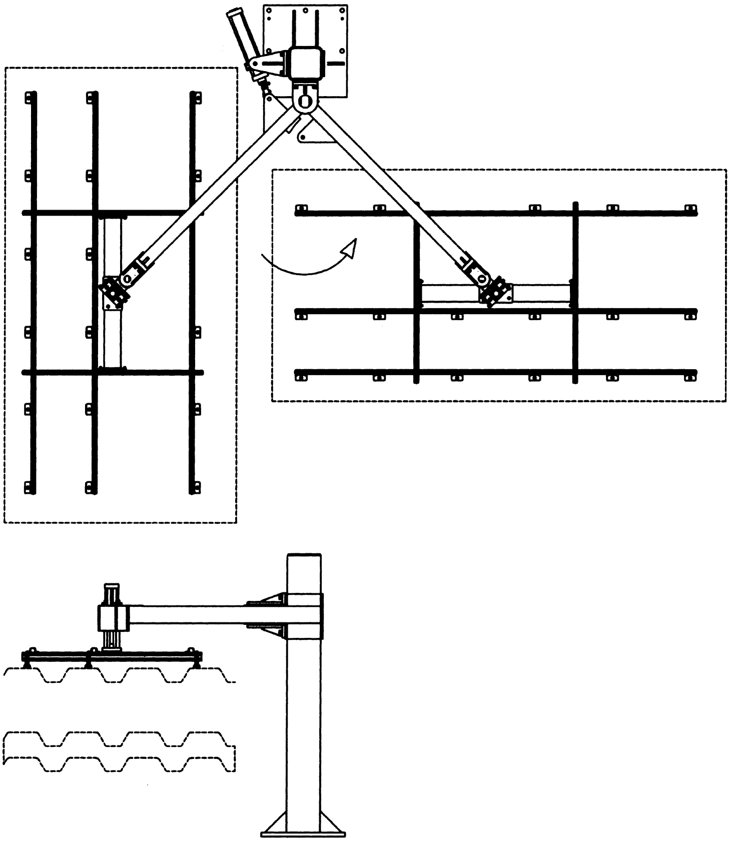


FIGURE 8.43 “Pick-and-place” unit rotates 90° and stacks roll-formed products. (Courtesy of CompuRoll Inc.)

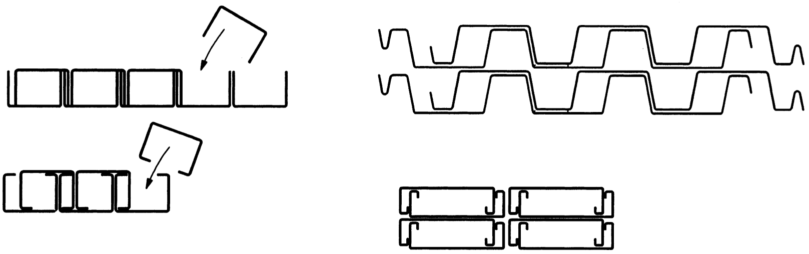


FIGURE 8.44 Piling nonnestable products by turning every second one over.

forward. The product can also be moved by magnetic rolls located above it. The suspended product will be moved into position then dropped either by demagnetizing the rolls or by pushing the product away from the rolls.

Finished products can be lifted up and moved sideways by an overhead vacuum (or magnet) "pick-up" unit (Figure 8.42). Robots can also be used to remove the finished products (Figure 8.43). The higher priced robot can only be justified if its speed matches the rate of production or if the finished products have to be placed in various predetermined locations.

It is difficult to make a stable bundle from nonnestable products. Products with 90° lips, "U" and "C" channels, or nonnestable panels can be better nested if every second product is turned 180° (flipped over). Bundles with every second product turned over are shown in Figure 8.44. Mechanical devices are available for this type of material handling, but they are relatively expensive. Turning over every second product may also reduce line speed. Therefore, wherever possible, the product designer should aim for products that can be nested.

8.9.2 Separating and Protecting Finished Products

Most roll formed products can be handled without taking special precautions; others such as stainless steel or aluminum with high gloss finish and some coated products have to be carefully handled and separated from each other.

After forming, assembling, and adding additional components, some roll formed products such as garden sheds, metal fences, baseboard heaters, sidings, and trims for the automotive aftermarket are placed directly into cardboard or other boxes, and sealed in the production line. The end user will receive the products in the same boxes.

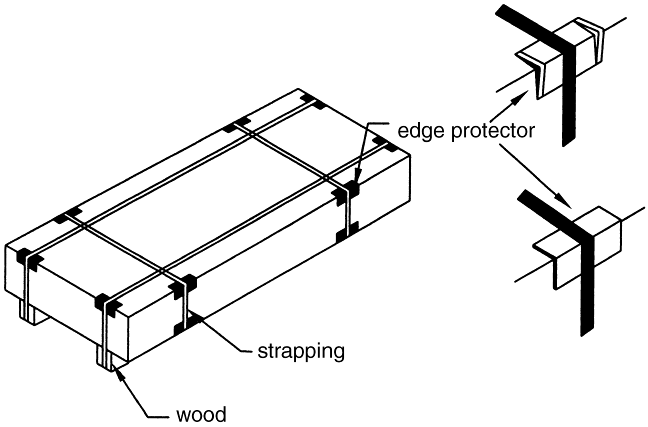
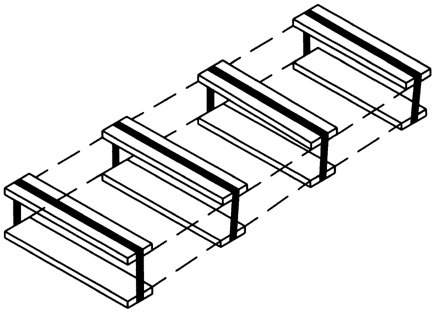
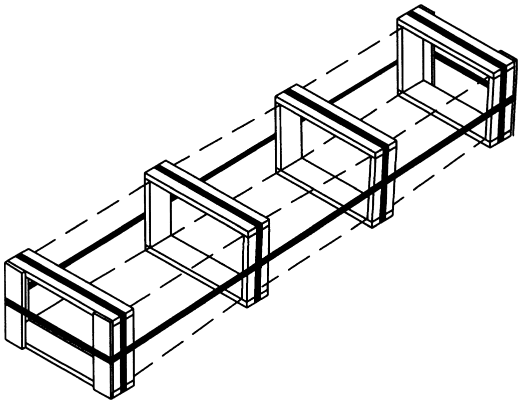


FIGURE 8.45 Corner protectors can prevent edge damage caused by strapping.

Other products sensitive to scratches are shipped in bundles, separated by paper, plastic or other soft materials. For many years after the introduction of precoated coils, roll formed prepainted products were separated from each other by interleaving with paper, polyethylene or other materials at the exit table. Interleafing is expensive and frequently the speed of the roll forming line had to be reduced. Improvements in the precoating systems and in the design of the product have eliminated most of the interleaving requirement for building sheets. However, there are still roll formed products for which interleafing is required for handling and shipping.



(a) for nestable panels



(b) for nonnestable panels

FIGURE 8.46 Wood protectors/separators strapped to bundles.

8.9.2.1 Strapping and Crating Finished Products

Several hundreds of pieces can be formed from each coil. To reduce handling time and protect the finished goods, the products are grouped together, handled, stored, and shipped in bundles, crates, boxes, or other shipping units. Bundling, crating, and packaging are expensive but necessary. Failure to provide enough protection could lead to substantial damages, complaints, and expensive replacements. On the other hand, overprotection could be too expensive and make the product noncompetitive. A balance has to be maintained. If products are too frequently damaged, then they are underprotected, but if there is never a complaint, then most probably the company spends too much for "overprotecting" the goods.

One of the simplest methods for bundling goods is to use two or more straps. Steel is the most frequently used strapping material. Plastic straps can be used for cardboard boxes or in cases when the straps are not exposed to sharp edges of the product. Strapping can be applied manually or automatically. In both cases, it is critical to apply proper strapping tension. If the bundle is loose, then the products slide out. If the strap is too tight, then the edges of the product can be damaged. To prevent edge damage, corner protectors are frequently used (see Figure 8.45).

8.9.2.2 Crating

To provide space for the forks of the forklift trucks or other equipment, the strapped bundles have to be separated from each other. The most frequently used separator is wood, usually low quality 2 × 4s.

The wood can be strapped to the bundles (Figure 8.46) to provide additional protection and to avoid the manual handling of individual pieces between bundles. There are endless variations of protection, from strapping pieces of wood to the bundles to elaborate, completely enclosed wooden crates.

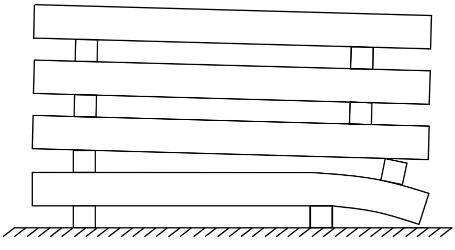


FIGURE 8.47 Misplaced support in piled bundles can damage the products.

When bundles are stocked on top of each other, it is important that the wood components supporting the load should be on top of each other. Misplaced supports can damage the bundles underneath them (Figure 8.47).

8.9.2.3 Boxes, Containers and Cradles

A variety of metal, wire, paper, plastic, and other containers are used by the industry to store and ship roll formed goods. The packaging material is dictated by price, type of product, storage, material handling, and shipping requirements, indoor or outdoor application, and temporary or final nature.

8.10 Finished Product Storage

The formed products may be stored for the next operation or for shipping. The storage can be within the plant building or outdoors.

8.10.1 In-Plant Storage

Most of the roll formed goods are stored inside the plant. To save valuable plant floor area, bundles or other products storage devices are stacked on top of each other, as high as practicality and safety permit.

8.10.1.1 Multiple Height Storage

Bundles, crates, tote boxes, cardboard boxes, and so on, can be piled on top of each other. The height of piling is restricted by the crush resistance of the bottom unit in the pile, the stability of the pile, the maximum reach of the truck or crane, the height of the building, and the frequency of need to remove packages from the middle or bottom of the pile. If bundle dividers or the bundle (package) lifting unit has to be manually positioned, then the safe reaching or climbing height can be a restricting factor.

8.10.1.2 Storage Racks

Storage racks are frequently used when quick access to any of the loads is required. This method is favored to store unitized pallets, tote boxes, and goods sensitive to piling and damage. Products stored in storage racks can occupy considerably more space than goods piled on top of each other. The distance between the storage rack columns also limits the length of products stored in racks.

8.10.1.3 Cantilever Racks

Cantilever racks are relatively expensive, but are occasionally used for storing long products such as building panels, if quick access to any package and good protection are important.

One shortcoming of all rack storage system is that occasionally packages are left and “forgotten” at higher storage levels.

8.10.2 Outdoor Storage

Building products, culvert pipes, and some other products can be stored outdoors. The biggest advantage of outdoor storage is its low cost. Its disadvantages are that, in most cases, extra precaution has to be taken against corrosion, pilfering, and loading and unloading in bad weather may not be convenient.

Nestable products and dense piles must also be stored at a slight angle to drain water. The water may originate from lubricant left on the product, rain, melting snow, or condensation. Products stored outdoors cool down during the night. During the day, the densely piled metal acts as a “heatsink,” and the water from the hot humid air condenses on the surface of the products. Excessive water can stain prepainted, stainless steel, or aluminum sheets and can create white and eventually brown rust on galvanized products. Unprotected “black” steel rusts so quickly that usually it is recommended that they are not stored outdoors.

In a humid sunny summer week without any rainfall, a single crate of building products, wrapped tightly in polyethylene sheet may generate 2 to 4 gal (8 to 16 l) of water inside of the package. Therefore, this method of protection should not be used.

8.10.3 Marking, Counting, and Weighing

Every bundle, and often every piece, must be identified by some kind of a marking.

8.10.3.1 Product Marking

In many instances, each piece must have a product and manufacturer's identification. The marking can be embossed in the manufacturing line by a rotary embosser, by stamping in the cutoff press, or by a separate device.

A simple way of marking the finished product is by handwriting. Although it is time consuming, the operator often has time to do it while waiting for the next product. In addition to the occasional illegibility, using an incorrect marking pen can cause the biggest problem. Inks that are not "weather- and sunproof" fade away. Opening the illegibly marked bundles to measure, remark and rebundle them again can take 5 to 10 times longer than it originally took to manufacture, mark, and bundle the product.

Ink stamping is simple and inexpensive; it can be done manually or by rolls. Labels can also be applied manually or automatically. Labels are more expensive but they can be colorful and contain more information. One common problem with labels is that if a plant runs out of label stock, the complete production line may have to be stopped.

Barcoded marking is gaining popularity with manufacturers of roll formed products. Many computer programs used in the plant generate the barcoded tags or labels.

Nonweatherproof ink used with rubber stamps or on labels can also fade away. Incorrect adhesive or label material creates additional problems.

Cardboard boxes are usually preprinted with product descriptions and advertisements. Bundles and crates may be marked with felt pens, stenciled, or more and more frequently with bar-coded labels.

Most marking problems are caused by human errors. Mismarking products can wreak havoc; therefore, education of employees is important.

8.10.3.2 Counting

To supply the right quantity of product is a basic requirement in any business. The number of pieces going into a package can be counted manually or by counters at the production line.

To minimize complaints, manufacturers occasionally supply a few "extra" pieces when shipping goods for larger jobs at distant locations, such as construction sites. In other cases, operators tend to place a scrap "protective" piece underneath or on top of the bundle to protect the goods. This well-intentioned gesture may backfire unless these extra pieces are well marked. It can happen that customers return the extra or scrap "protective" pieces for credit.

8.10.3.3 Weighing

The starting material for most roll formed products is purchased by length or weight. Products are usually sold by other units, such as number of pieces or linear or area measurements. If roll formed products are sold by weight, it is important that the plant use a scale accurate enough to meet legal requirements.

8.10.4 Truck Loading

Finished roll formed products occupy considerably more space than the coils (Figure 8.48). They require extra protection and careful handling. Therefore, the method of loading outgoing shipments is an important part of plant layout and equipment selection. Most products are shipped by trucks. Railway cars and containers are seldom used.

The method for loading trucks depends on the:

- Type of product
- Method of packaging

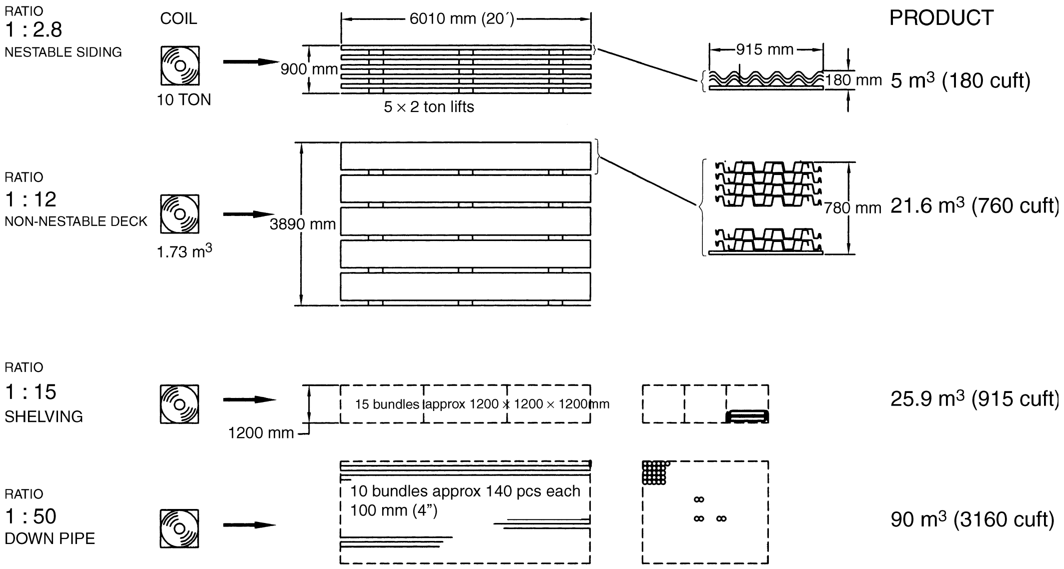


FIGURE 8.48 Finished products occupy 2 to 50 times more space than coils.

- Sensitivity of product to transportation
- Loading facilities
- Unloading facilities at the receiving end
- Protection requirements during transportation
- Weather conditions
- Weight, length, and width restrictions
- Safety requirements
- Other specifications (e.g., export shipment, protection against pilferage, etc.)

8.10.4.1 Type of Trucks

8.10.4.1.1 Closed Van

Closed vans are used if good protection against weather is required or when open bed trucks are not available. Loading, unloading, and access to products behind the last load in the van are restricted.

Vans are usually loaded (and unloaded) with low mast trucks or other rolling-lifting equipment that can enter the vans. Therefore, "dock-level" loading (bed of the van in level with the shipping area floor, as shown in Figure 8.49) is required at both the shipping and receiving ends.

Special vans, which handle standard size pallets or skids, may be equipped with floor conveyors. These conveyors support the load only during loading and unloading, and they eliminate the need for material handling equipment entering the van.

8.10.4.1.2 Open Bed Trucks and Trailers

Open bed trucks and trailers are loaded by cranes, trucks, or other material handling equipment. Products are accessible along the full length of the truck (trailer) bed. However, it takes more time to remove and install sides and cover (tarpaulin) if such extra protection is required. A big advantage of the trailers, in

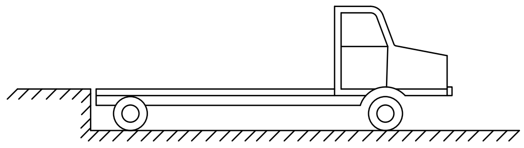


FIGURE 8.49 Dock-level loading of truck.

addition to their size and large capacity, is that they can be "dropped" at both loading and unloading points while the cab is hauling other trailers.

Open bed trucks and trailers can be loaded and unloaded by cranes or trucks both indoors and outdoors. Some special trucks are equipped with self-loading/unloading cranes. This feature can be useful at job sites or other locations where material handling equipment is not readily available.

Dock-level loading of open bed trucks and trailers is also feasible. The advantage of dock-level loading is easy access to the truck bed for the material handling personnel. The disadvantage of the arrangement is the existence of large pits if they are inside the plant.

8.10.4.2 Truck Routes Inside and Outside of the Plant

Insufficient truck loading/unloading locations and facilities create delays, as well as production and shipping problems. Excess facilities require excessive investment and result in unnecessary space.

Vans are usually parked outside the building backing to a truck door for level loading/unloading. Sufficient yard space must be provided for maneuvering truck back and forth from the road to the doors.

In-plant loading of open bed trucks and trailers can be arranged by backing into the building or driving through it. Drive-through is faster and safer but requires more space. In-plant loading provides weather protection. It is important to provide adequate drainage around the truck loading areas. Rainwater or melting snow should be drained to avoid water running into the storage areas.

8.10.5 Railway Cars

In the case of long, heavy, or highly piled products, it can be an advantage to ship them in railway cars. When using gondola cars, loading must be at floor level. Flatbed railway cars can be loaded by crane, but easy access to the cars must be provided. If railway access is from one direction only, then time-consuming shunting is required. If a drive-through arrangement is feasible, then moving the "train" in one direction is easier to arrange. In the case of long trains, protection (closing doors) is more complicated. Shipping roll formed product by rail is less and less frequently used.

8.10.6 Containers

Container shipments are occasionally required for overseas export and other special cases.

8.11 Material Handling Equipment

8.11.1 Forklift Trucks and Side Loaders

Forklift trucks are frequently used material handling equipment when:

- Volume is low
- Products are handled in tote boxes
- Capital funds are restricted or only a forklift truck is available
- Building is not designed for a crane
- Installation of extra support and foundation for crane rails is not practical
- The ceiling of building is too low
- The building is rented or the operation is temporary
- Box cars or closed vans are used for transporting coils
- Coils have to be moved from one bay to another

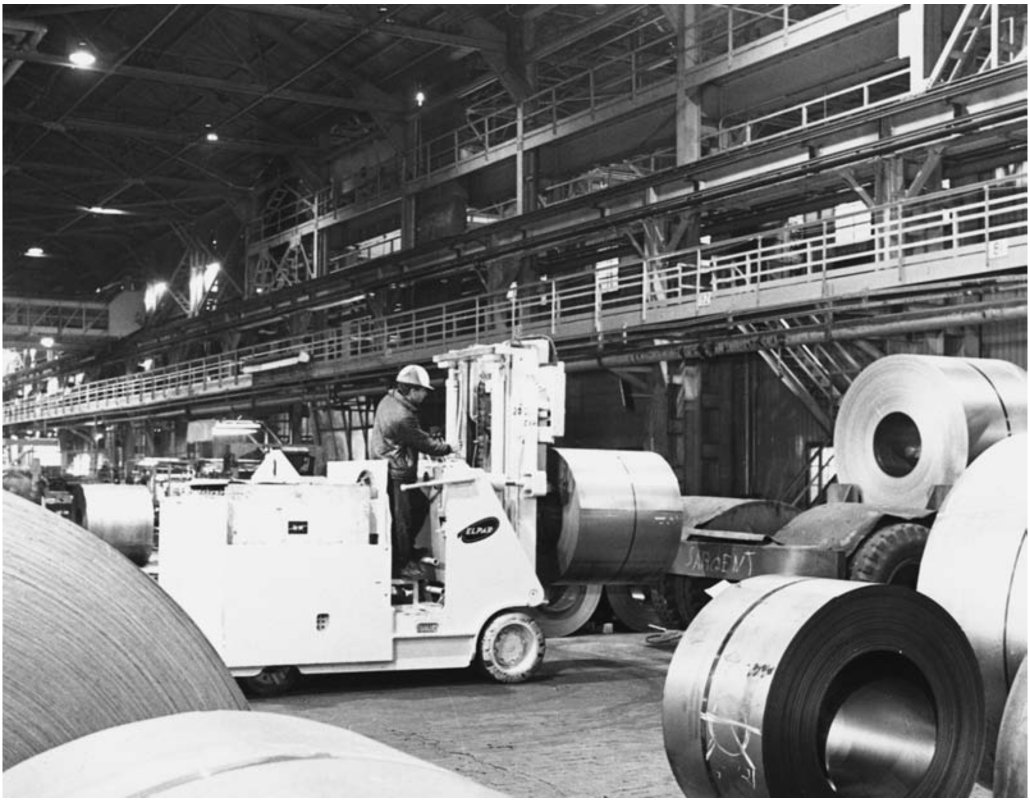


FIGURE 8.50 Forklift truck with "bull-nose."

The greatest advantage of the forklift trucks is their low cost and versatility. The disadvantages are the relatively large plant area taken for truck isles and large spaces needed for turning and maneuvering. In some plants, coils cannot be loaded by forklift truck directly into the line.

Standard forks are used to move coils on pallets or skids, especially with vertical axes. Occasionally, forks are inserted into the horizontal core or are at the outside of the coil. The concentrated forces at the edges of the forks may damage several laps of some thinner, softer, or sensitive type of material.

Special "bull noses" (see Figure 8.50) and other attachments are available to minimize the damage to the inner core, but they are not suitable for loading coils directly onto uncoilers. Forklift trucks can be used for handling relatively short finished products in tote boxes or pallets, but they are not suitable to move long products, such as building panels. Side loaders are similar to the forklift trucks but the forks are at the side. They can move sideways, pick up the load, and then travel in the longitudinal direction. Because of this maneuverability, they can handle long loads but still require wide isles and very large turning space. Therefore side loaders are usually not the best choose for handling roll formed products.

8.11.2 Cranes

Coils or stacks of sheets are handled with the following types of cranes:

1. Overhead
2. Stacker
3. Jib
4. Gantry
5. Monorail

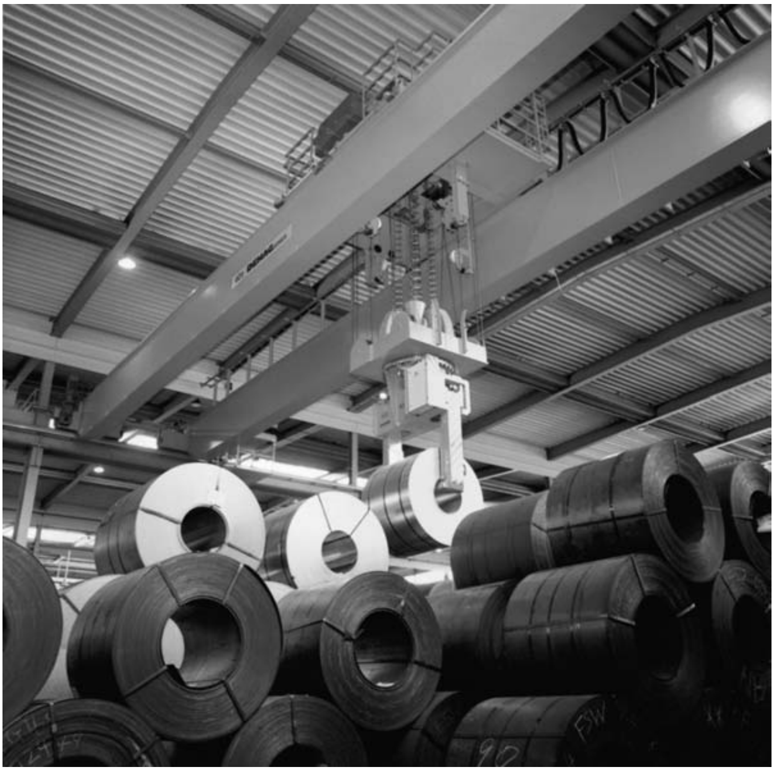


FIGURE 8.51 Overhead crane handling coils with telescopic coil grab. (Courtesy of Demag Cranes & Components.)

8.11.2.1 Overhead Cranes

Overhead cranes, such as shown in Figure 8.51 are the most frequently used and the most efficient handling equipment for lifting and transporting material through the plant from receiving to shipping.

An overhead crane does not occupy valuable floor space, it is versatile, and it can handle coils or sheets. It can be used to unload incoming material from open bed trucks or railway cars, move material into or from storage, load roll forming lines, and handle finished products.

One well-chosen crane can serve all the coil receiving, coil storage areas and up to 8 to 12 roll forming lines, depending on:

1. Coil sizes
2. Coil upending and weighing requirements
3. Distance to be traveled from point of unloading to coil storage, and from coil storage to equipment
4. Method of coil storage and layout
5. Availability of in-line storage and loading facilities
6. Frequency of removing partially used coils
7. Speed of roll forming line
8. Time spend to "dig out" coils
9. Availability of proper below-hook attachments
10. Efficiency of crane operator

When selecting a crane, the primary consideration should be its ability to perform its function in the most economical way. A breakdown of the coil handling crane can stop the production of all roll forming lines and other operation in the plant.

The span of the crane is usually determined by the building. The lifting capacity to hoist the combined weight of coils and below-hook attachments is determined by the capacity of the uncoilers and by future plans.

The required performance will determine the service classification of the crane. The classification commonly depends on the weight, lifting distance, and number of lifts per hour. However, operating speed, environment and ambient temperature, products handled, percentage of lifts made at rated capacity, number of motor starts, reliability of supplier, and availability of service and spare parts will also influence crane selection. In many roll forming plants, a less costly Class "C" (moderate-duty) floor or remotely operated crane is adequate.

For heavy-duty performance, a Class "D" (heavy-duty) floor, cab, or remotely operated crane should be selected.

Cab operated cranes are controlled by a master switch or push buttons. They usually provide up to five speed points for hoist and three to five points for trolley and bridge travel. Floor operated cranes by a pendant control usually provide only two hoist speeds.

The bridge travel speed has to be restricted to walking speed when operated with pendulum. Remote radio control is frequently the most economical method to operate cranes in secondary metal manufacturing plants.

Top-running cranes are preferred over underhung cranes because of simplicity in maintenance and rail alignment.

8.11.2.2 Stacker Cranes

Overhead cranes with stacking attachment provide the best combination of cranes and forklift trucks. They are ideal for plants requiring quick access to any coils stored in racks. Therefore, stacker cranes are frequently used by the shipping department of primary metal coil manufacturers, coil coaters, and steel centers as shown in Figure 8.1.

Stacker cranes, however, are one of the most expensive handling units. The stacker unit usually weighs more than the coil itself, requiring larger foundation and stronger structure. The high cost of the stacker crane, the cost of storage racks, and extra space usually prohibit the use of this type of equipment at roll forming plants.

8.11.2.3 Jib Cranes

This type of crane is restricted in lifting capacity and the area they can service. Individual jib cranes, however, can be useful in making the roll forming operator less dependent on forklift trucks or cranes when narrow strips or coils are frequently loaded on or unloaded from uncoilers.

8.11.2.4 Gantry Cranes

Gantry cranes are seldom used to handle coils. However, they can be handy substitutes when the available plant structure is insufficient to carry an overhead crane, in circumstances where adding a new foundation and crane supporting structure would be too expensive, or the plant is rented or operation is temporary. The advantage of the gantry unit is its lower cost compared to overhead crane and that it can be easily transferred to new location. The disadvantage is the additional floor space taken by the rails, possible truck traffic and walking problems because of rails protruding from plant floor, and the gantry unit is slower than overhead cranes and more cumbersome to handle it.

8.11.2.5 Monorails

Monorails with hoists are restricted to handle lightweight coils and only underneath the rails. This restriction makes the monorail units the least practical for coil handling.

8.11.2.6 Yard Cranes

Different types of cranes or unloading equipment can be used for coils to be unloaded and occasionally stored outside the plant. For reasons mentioned earlier, in-plant handling is preferred, limiting the application of yard cranes for coil and sheet handling.

Occasionally, overhead crane supporting structure and rails are extended from the plant into the yard, allowing unloading outside the plant and moving coils, in one handling, to inside storage. This method is less frequently used in harsher climates, because the large opening needed for the crane to enter the plant can create problems in winter or on rainy, humid days.

8.12 Material Handling Accessories

8.12.1 Crane Attachments

Auxiliary equipment attached to cranes is used to lift, move, rotate, weigh, and load coils or bundles of sheets. Equipment cost, available headroom, storage space, isle width, coil orientation, type of storage, method of line loading, limitation in equipment, and structure can determine the type of crane attachment to be used.

Well-selected lifting attachments will reduce handling time and can reduce the material handling crew to one person.

If the crane handles only one type of product, then the attachment can be permanently left on the crane hook. If the axes of the coils are rotated from vertical to horizontal, coils, sheets, and finished products are handled by the same crane, then several below-hook attachments will be required.

8.12.2 "C" Hook

The "C" hook is one of the most frequently used attachments to handle coils with a horizontal axis (see Figure 8.52). It is simple, has no moving parts, and is inexpensive. The disadvantage of the "C" hook is the isle space required to insert and remove hook from coils (Table 8.1).

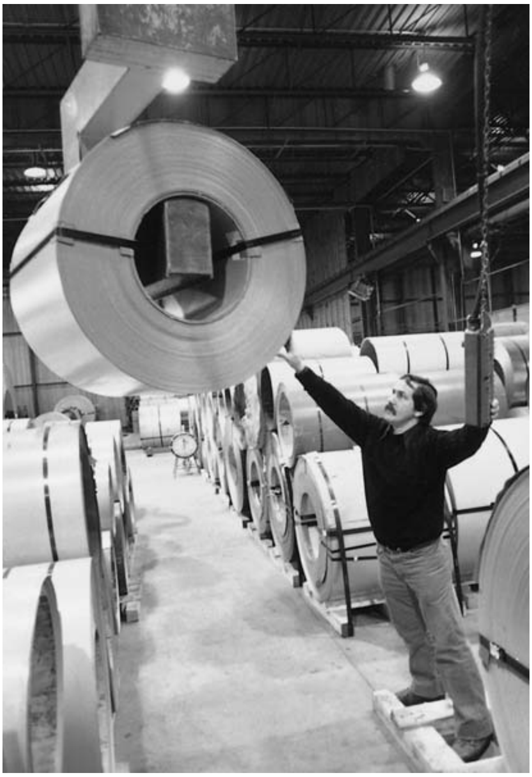


FIGURE 8.52 "C" hook coil lifter.

TABLE 8.1 "C" Hook and Coil Grab

"C" Hook		Coil Grab	
Advantage	Disadvantage	Advantage	Disadvantage
Simple	Increased coil storage space required	Requires less coil storage space	More expensive
No moving parts	Cannot load coil on uncoiler	May load on uncoiler directly	Higher headroom required
Less expensive	Usable only for coils with horizontal axis		Coil widths must be within specific range
Can handle wide range of coil widths			Applicable only for coils with horizontal axis

8.12.3 Coil Grabs

The two vertical, moveable arms of the telescopic or parallelogram coil grab, shown in Figure 8.51 and Figure 8.53, can reach into the inside core of the coil. The small horizontal, grabbing movement allows for leaving only a minimal, approximately 12 to 18 in. (300 to 450 mm) of space between rows of coils. However, it usually requires more head room than the "C" hooks. This either restricts the number of coils piled on top of each other or increases the crane hook and plant ceiling height.

The telescoping type of coil grab needs less headroom but more space between the rows. The gain in additional storage space due to the small isle requirements usually far outweighs the small purchase price difference with respect to "C" frame and the extra cost attributed to a higher building.

Figure 8.53 provides a graphic illustration of the isle space requirement when coils are handled with forklift truck or crane with "C" hook or coil grab attachment.

8.12.4 Fork Attachment

As mentioned earlier, the "C" hooks are limited to handling only coils with horizontal axes. To lift coils on pallets, or bundles of sheets, crane attachments with forks are available. Forks may be directly attached to the stacker cranes or supplied as underhook "C" units.

8.12.5 Below the Hook Coil Upenders

There are below-hook attachments available, which lift the coils with vertical axes and rotate them into horizontal position in one handling. A typical attachment (shown in Figure 8.54) provides a simple, timesaving method for lifting and upending narrow coils.

8.12.6 Slings and Chains

Metal or fiber slings going through the coil core can be used to handle coils if loading/unloading is at floor, or easily accessible, level. Fiber (nylon or other) slings should be frequently checked for damage. Metal slings may damage the inside edges

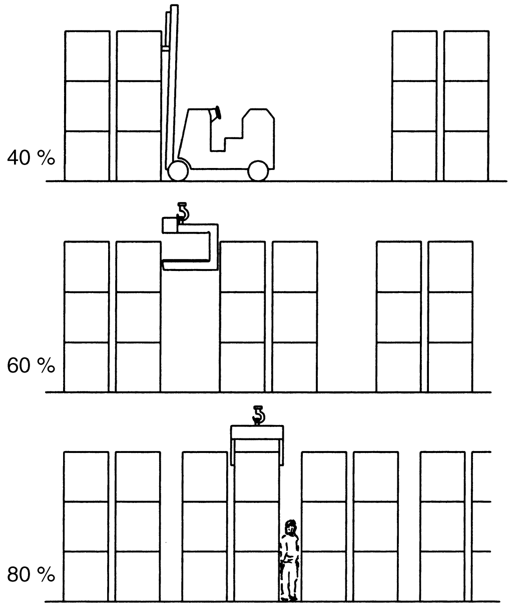


FIGURE 8.53 Coil storage isle width depends on the type of handling equipment.

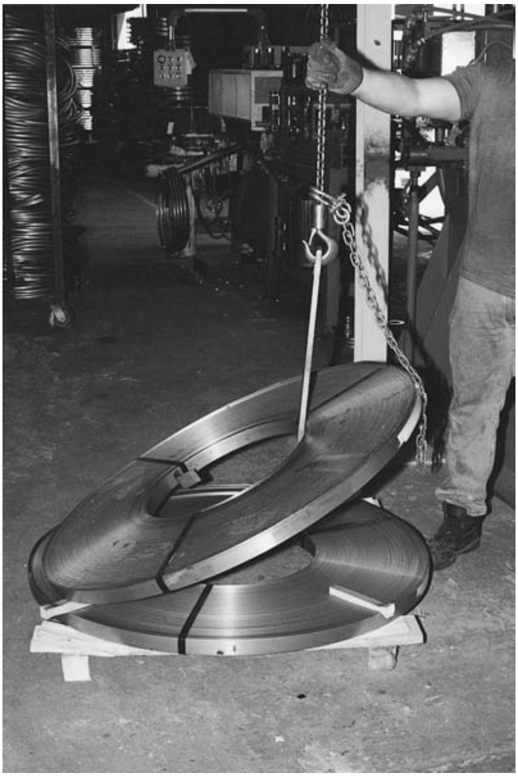


FIGURE 8.54 Combined coil lifting and upending of narrow coils.

of the coil. Slings or chains are sometimes applied to narrow coils with vertical axes, and they can be used to rotate into horizontal position during lifting.

Chains and ropes may damage the edges of thinner or softer metal coils and therefore their usage should be restricted.

8.12.7 Other Crane Attachments

Coil orientation, receiving and inventory policy, weighing, or other requirements may require the application of additional attachments separately or in conjunction with the previously described below-hook attachments.

8.12.7.1 Rotating Crane Hook

If possible, the direction of the horizontal coil axis on the incoming transport vehicle, in storage, and on the uncoiler, should be the same. Unavoidable conditions, however, may make it necessary to change the direction of the horizontal axis of the coils or rotate it, for example, from north/south to east/west direction.

Coils hanging on the swivel hook of the crane can be rotated by hand after lowering the load to near-floor level. Motorized rotation is preferred, however, to increase efficiency and reduce material handling time. A motorized rotating hook can be ordered with the crane, while coil grabs and some other units may be purchased separately with rotating attachment.

8.12.7.2 Crane Scales

If the weight of the incoming, stored, or outgoing material has to be checked, then using a crane scale can save time and floor space. A large variety of mechanical, hydraulic, and electronic crane scales are available with different accuracy. Crane scales are available with optional features such as printout and direct or radio data transmission to production/inventory control departments or computers.

8.13 Crane Controls

Most crane controls are located either hanging on pendulum, or in a cab or crane, and attachments may be controlled by radio.

8.13.1 Pendulum Control

Pendulum hanging from the crane is the lowest cost and simplest method of operating crane. As the operator walks with the crane, the crane speed and the distance covered is restricted. A clear walkway through the plant for the operator and for the load is required.

8.13.2 Control in Cab

The controls and the operator can be located in the cab traveling with the crane. The cab is either located underneath one end of the crane bridge or, in the case of the stacker crane, may be attached to the stacker unit. This provides greater comfort when operating the crane, but the operator is confined to the cab all day. In most cases, an additional “ground” crew is required, increasing material handling costs.

8.13.3 Radio Control

A radio transmitter unit with all control functions hanging on straps from the operator’s neck allows the remote operation of the crane from a safe but desired distance. The operator can perform additional functions such as inventory control, load manipulation, and so on. One operator can easily unload coils from transport vehicle or storage space, and then weigh, mark, and load roll forming lines.

8.14 Plant Layout

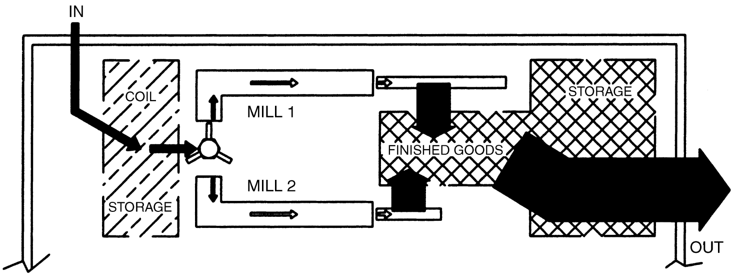
Moving the material through the plant is a necessary part of the manufacturing process. The labor involved in moving the products does not increase the value of the product, only its cost. In most manufacturing plant, the actual time spent on moving the material in the plant is more than the time required to form the product. Therefore, a proper plant layout and an efficient method of handling and storing both the starting and finished products have a significant effect on product cost and profit. The volume of the finished products after roll forming can be 2 to 50 times the volume of the coil. The expansions of a few typical products are shown in Figure 8.48.

Owing to the “expanded” volume, both the storage space and the number of “lifts” to move the finished products is multiple of those required for coils. Layout of the plant has to take this fact into consideration.

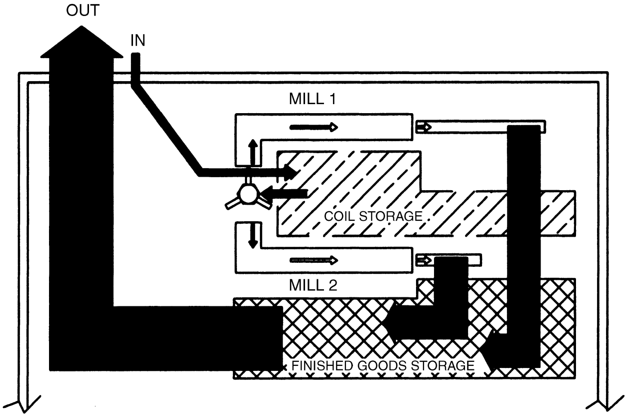
Plants with several roll forming lines usually have one high-capacity crane dedicated to unload the incoming coils, transfer them into the storage area, and from storage to the uncoilers. More equipment and a considerably larger storage area is required for the finished products removal, storage, and loading of outgoing trucks.

8.14.1 Flow of Material

To reduce the material travel time and expenses, it is important to provide as short and smooth flow as possible (see Figure 8.55). Excessive crane or other equipment travel, even if it is only 10 to 20 ft (3 to 6 m) at a time, can be a considerable expense when the total number of lifts is considered during the life time of the equipment working in the plant.



(a) GOOD FLOW



(b) BAD FLOW

FIGURE 8.55 Flow of material through the plant.

The following should be considered when plant layout is prepared and equipment selected:
Material Flow: “IN”

- Yearly quantity (weight and number of lifts)
- Peak quantity (number of lifts per shift)
- Transportation method of incoming material (railway: gondola or box cars; truck: open bed or closed vans)
- Material handling equipment and unloading at receiving point
- Method of weighing (if required)
- Method of coil or strip storage (pile, rack etc.)
- Weight and size of coils
- Orientation of coils (center line or eye of coils — horizontal or vertical)
- Coil packaging (band, skid, with or without core, etc.)
- Susceptibility of material to environment (warehouse conditions)
- Snow, water, dirt removal at receiving
- Inventory administration (coil identification and necessary administration)
- Number of mills to be served (present and estimated future equipment)
- Auxiliary equipment (upender, turnstile, storage rack, coil car, etc.)
- Frequency of returning partially used coils to storage
- Special care in handling and storage (protecting surface, edges, high value of material, etc., if required)
- Separate storage space for rejected or damaged coils

Material Flow: “OUT”

- Material handling equipment at the product unloading and shipping point
- Type of transportation equipment (truck, railway)
- Auxiliary equipment at the exit of the lines (conveyor, power conveyor, drop table, drag chain etc.)
- Bundle or package size (weight, width and length)
- Packaging, strapping, or crating requirements
- Feasibility of loading directly from line on to transportation equipment
- Indoor or outdoor storage requirements
- Method of weighing outgoing shipment (if required)
- Storage method (stacking, storage racks, crates, tote boxes, etc.)
- Stackability of products (bundles, boxes, crates, etc.)
- Storage space requirements for subsequent operation (if any)
- Short duration or seasonal, long duration storage requirements
- Capability to ship any of the stored packages or bundles (opposite to “first in, first out” or “first in, last out” method)
- Sensitivity of material to storage conditions (humidity, temperature, dust)
- Necessity to handle certain products with special care to avoid scratching, bending, and so on
- Orientation of products (direction of long pieces in relation to material handling and transportation equipment)
- Shipping or production priorities (e.g., priority to load customer’s truck versus unloading roll forming mill)
- Availability of equipment, labor and other services (such as lights at outdoor storage) if afternoon and night shift work is required
- Lifting height restrictions (e.g., lifting crates over the side support of railway gondola cars).

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9

Designing Products for Roll Forming

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George T. Halmos
Delta Engineering Inc.

9.1 Developing Light Gage Products

The forerunners of the presently used light gage metal building, drainage, grain storage, appliance, automotive, and other products were developed decades ago by trial and error. Tinkerers and designers recognized that the principles of strength calculations developed for thick materials, plates, and structural components have limited or no applicability to light gage materials.

It was only in the early 1940s that significant research commenced on cold formed, light gage, steel structures, spearheaded by Dr. George Winter at Cornell University and followed by a long line of other researchers in North America, Europe, and other parts of the world. Since then, the behavior of thin, light gage, metals under strain have been thoroughly studied. The result of these works became the foundation of the present specification for the Design of Cold-Formed Steel Structural Members by AISI [382] and other design guidelines.

The load carrying capacity of light gage components is frequently restricted by the buckling of compressed, flat elements. Therefore, the present codes allow for consideration of the cross sections of all bent elements, but only those flat elements, which do not exceed a specified width:thickness ratio limit. In several codes, the width:thickness ratio is limited to approximately $w : t = 60$.

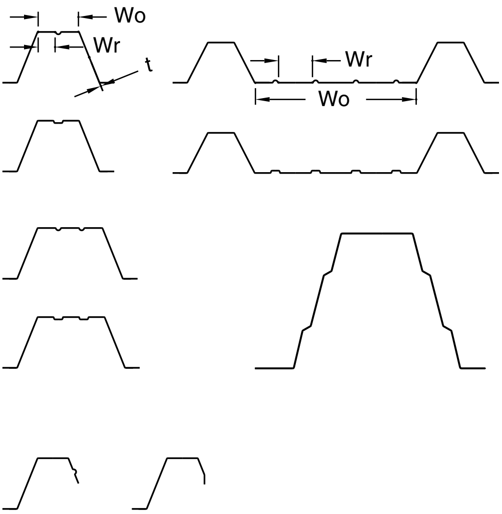


FIGURE 9.1 Different stiffener ribs and heads.

To utilize all or most of the compressed elements, edge stiffeners and simple or multiple stiffener elements can be added to the sections. Figure 9.1 shows some typical stiffened sections.

This chapter provides practical guidelines for the application of design principles to roll formed products without repeating the information and equations provided in the specifications and books.

Designers have a significant influence on the quality of the product, as well as on the tooling, equipment, and production cost by selecting the best bending radii, choosing the best shape of stiffeners at the practical locations, and keeping holes, notches, and embossments at the practical distance from bend lines and other variables. Frequently, the success or failure of the products as well as the profit of the company is heavily dependent on the judgment and expertise of the product designers.

9.2 Design Considerations

The product design is influenced by many requirements such as:

- Function of the parts or assembly
- Strength requirements; static and dynamic loads, fatigue, impact resistance, and others
- Assembly or erection requirements
- Appearance, styling, and customer's requirement
- Repair or interchangeability, replacement methods
- Safety standards or common sense safety considerations
- Welding, painting, plating, packaging, and other requirements
- Corrosion, erosion, friction, wear, heat, or other exposures
- Vibration, noise, or heat transfer
- Availability of material (including company's own inventory)
- Special requirements such as crash energy, military, and so on
- Quantity per production run and total quantity per year or tool life

A well-designed product, which meets all the above conditions, still cannot succeed unless it meets with the following two additional requirements:

- Manufacturability
- Competitive cost per piece and total equipment and tooling cost

9.2.1 Influence of the Forming Procedures on Design

Both brake forming and roll forming provide straight bend lines. During brake forming, the cross section is uniformly changed along the full length of the product. Major stresses are restricted to the bent elements and their nearby vicinity.

Roll forming, however, is a progressive process. While one end of the strip is flat, the other end is completely formed (Figure 5.1 and Figure 5.11). Stretching and compressing elements of the strip, with or without prepierced holes, notches or embossments, leaves residual stresses in the product. Excessive residual stresses result in camber, twist, cross-bow, edge or center waviness, herringbone effect or other deviations from straightness and flatness shown in Figure 4.1 and Figure 10.38d–l.

Product design has a significant influence on both the residual stresses developed during forming, and the achievable tolerances.

9.2.2 Selecting Bending Radius

To form a flat strip to the specified shape, the stresses in the bent elements must exceed the yield point. It is generally accepted that the stresses exceeding the yield point and resulting in a permanent deformation develop over 0.2% permanent elongation. In cases involving mild steel, the total strain at this point will be in the magnitude of 0.6 to 0.8%, or a multiple of that when higher strength steel or aluminum are formed. To achieve a permanent deformation, or "set" as frequently described in roll design terminology, the outside fiber of the bend line should be stretched from a minimum of approximately l to 2% to the maximum strain attainable without material failure (Figure 6.9).

For the above reason, roll designers prefer to form the bend lines with a relatively small radius. The large elongation at the outside fiber of the bend line creates stresses well over the yield point and "sets" the shape with minimum springback. When bending to a large radius, the stress will be barely above the yield point and the elastic strain/permanent strain ratio will be high, resulting in a large springback.

The percentage of elongation over the outside fiber (Figure 9.2) can be calculated as

$$e_\mathrm{e} + e_\mathrm{p} = e = \frac{a_\mathrm{o}}{2r_\mathrm{n}} \times 100\%$$

where

e_e = elastic strain
e_p = permanent strain
e = total strain in percentage
t = thickness of material
r_n = bending radius at actual neutral axis of strip
r_i = inside bending radius
k = bending factor
a_o = distance of the outside fiber from the actual neutral axis or $a_\mathrm{o} = (1 - k)t$

Example

if $r_\mathrm{i} = 2t$ and $k = 0.33$
then $r_\mathrm{n} = 2t + 0.33t = 2.33t$

and

$$e = \frac{(1-0.33)t \times 100}{(2+0.33)t} = \frac{0.67 \times 100}{2.33} = 28.75\%$$

whereas

$$\text{if } r_\mathrm{i} = 80t, \qquad \text{then } e = \frac{0.67 \times 100}{80.33} = 0.83\%$$

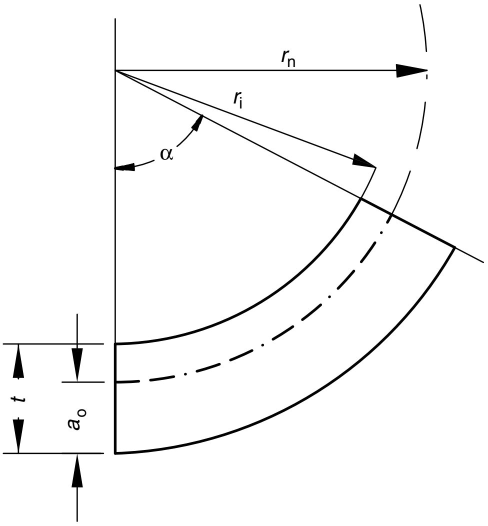


FIGURE 9.2 Theoretical approach to calculate the elongation of the outside fiber.

The above calculations are based on the incorrect assumption that the deformation is restricted to the curved element only. In reality, the strain is extended for the curved elements to the adjacent straight part (Figure 5.87b). As a result, the actual strain will be less than the calculated one.

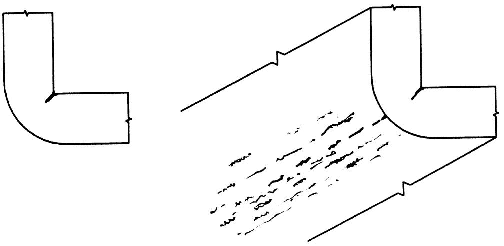


FIGURE 9.3 Forming "scored" bend lines can lead to fatigue cracks or surface cracks.

However, the above examples still clearly indicate that bending to a small radius will create a large strain, while bending a metal in a radius equal to 80*t* (80 times thickness); the total elongation will be so small that it will not create permanent deformation at all. That is the reason why large diameter process rolls are used in coil-processing lines, when permanent curving of the strip in the longitudinal direction must be avoided. For the same reason, the inside wraps of coil above a certain thickness (with smaller $r : t$ ratio) may remain permanently curved while the outside wraps (with larger $r : t$ ratio) will spring back to practically straight.

In most cases, the minimum bending radius can be determined from bending charts provided by metal suppliers, and from the thickness, mechanical, and other properties of the material. Using special roll forming techniques, however, sections with radii smaller than that specified in the charts can be formed. Figure 5.17 shows some alternative methods for forming sharp inside radii. These methods should be used cautiously when strength is critical, when the product is exposed to fatigue, or when the cracking of the parent material or coating can be detrimental (Figure 9.3).

Table 9.1 provides a guideline for typical minimum bending radii. For more detailed data, see supplier's recommendation, available standards or conduct bending tests.

TABLE 9.1 Guide to Minimum Bending Radii

Material	Coating	Yield up to	Elongation	*R*/*T*	Notes
Steel	Uncoated	45,000 psi, 310 MPa	over 18%	0, 1 to 2	If specified in ASTM or other standard
Steel	Galvanized			0, 1 to 2	If specified in ASTM or other standard for zinc thickness up to 275 g/m^2
Steel	Painted			2	For elastic paints and laminates
Steel				1 to 2	For paints heated before forming
Steel				3 to 4	For less elastic paints and laminates
Steel	Uncoated, galvanized painted or laminated	60,000 psi, 410 MPa		2 to 3	
Steel	Uncoated, galvanized painted or laminated	80,000 psi, 550 MPa	over 1 to 2%	4 to 5	
Steel	HSLA	100,000 psi, 690 Mpa		3 to 4	
Steel	HSLA	140,000 psi, 965 MPa		4 to 5	
Steel	HSLA	180,000 psi, 1240 MPa		3 to 4	Dual phase, martensite, inclusion controlled
Aluminum		20,000 psi, 140 MPa	over 20%	0 to 1	
Aluminum		25,000 psi, 170 Mpa	over 2 to 3%	2 to 3	
Cooper					Depending on mechanical properties
Brass					Depending on the type
Zirconium					Depending on the type

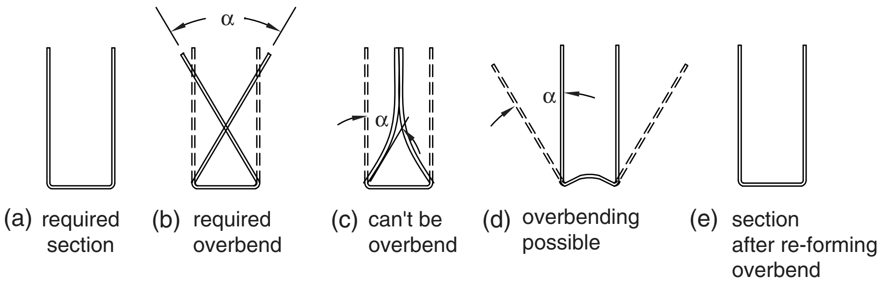


FIGURE 9.4 Materials with considerable springback may have to be formed in unusual ways.

Comments

1. Manufacturing bending charts occasionally show the minimum diameter of a mandrel around which the material can be bent (d:t ratio). The commonly used term of minimum bending radii $r : t$ will be half of that value.

   Example: if $d : t$ is 2, then $r : t$ is 1.

2. Microalloying and inclusion control of USHH (ultra high strength steel) can reduce the minimum bending radius:thickness ratio from 6–7 to 3–5; for correct information, consult supplier.
3. The guaranteed mechanical properties of many high strength, low alloy, dual phase, and other types of steel are achieved with the combination of alloying, heat treating and cold rolling. Mechanical properties usually refer to values in the direction of rolling. Yield, UTS, and elongation perpendicular to the direction of rolling, which are critical to the bending during roll forming, can be in a wider range, influencing both minimum bending radius, and springback.

Springback of these high strength and work-hardening materials can be as high as 25 per 90° bend. In other words, to achieve a 90° bend, the material may be formed to 115°. The designer shall provide space in the cross section for the overbending (see Figure 9.4) or consider false bending.

9.2.3 Designing a Product with a Large Radius

The calculations shown in the previous example demonstrate that if the inside radius is equal to $80t$, then $e = 0.8\%$. The largest portion of the 0.8% elongation is elastic and the smaller portion is permanent strain. Even with a smaller inside radius, ($r = 10t$ or more) the large springback makes it very difficult, if not impossible, to roll form consistent cross sections (see Figure 9.5). For additional details on roll forming products with large radius see Chapter 5.

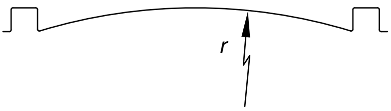


FIGURE 9.5 Roll forming to large radius is very difficult because the considerable springback.

9.2.4 Minimum Bending Radius of Coated Products

The minimum bending radius (minimum $r : t$ ratio) of coated metals is a function of the elasticity of both the parent material and coating. The surface cracks of zinc, and other metallic coatings, paints, or laminates usually are very small and hardly visible to the naked eye. However, the discontinued coating will greatly reduce the corrosion resistance of the product. Coating discontinuity can be caused also by excessively high pressure between forming rolls, high surface speed differential between top and bottom rolls, incorrect setup, inadequate lubrication, or scratching of the surface by entry guides, cutoff dies, or other components. The effects of corrosion, owing to damaged coating, will be visible in a short time.

Water penetrating through the paint cracks will generate zinc carbonate (white rust or storage stain) at the bend lines of prepainted, galvanized steel. After all the zinc, at and around the bend line, is transformed into zinc carbonate, the unprotected steel starts to corrode and "red" rust will appear on the surface (see Figure 9.6).

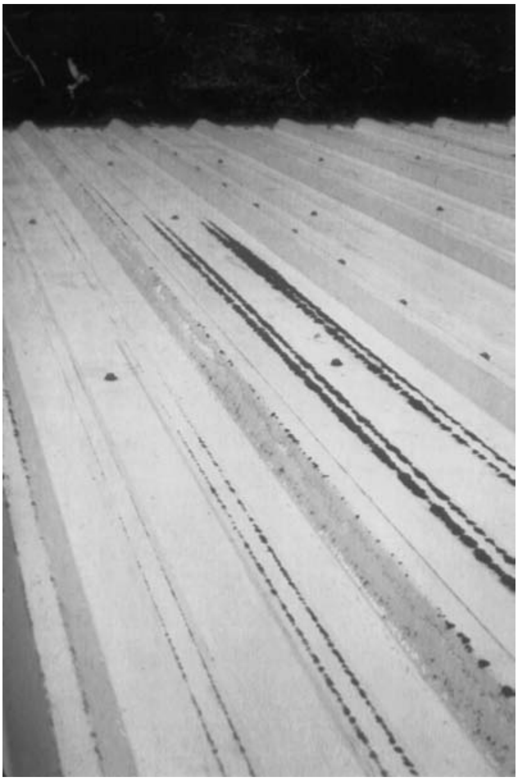


FIGURE 9.6 Cracked coating leads to premature corrosion.

9.2.5 Minimum Bending Radius of Presheared/Prenotched Metals

During shearing, notching and piercing, the cutting die first "shears" through a part of the metal then, after a certain degree of penetration, the rest of the sheared surface will "break" away. Figure 5.22 and Figure 6.10 show the edge of a sheared metal.

It is not unusual to see 1/4 to 2 in. (6 to 50 mm) long cracks at the end of brake formed bend lines. The cracks usually are initiated by the rough, broken away surface of the sheared edge. Continuous roll forming will not exhibit such a problem but edge cracks may develop at the end of the products if higher strength, thicker metals are precut or notched before roll forming and then rolled to a tight radius.

9.2.6 Minimum Radius of Embossed Metals

Decorative or functional embossing of metals is achieved by either forming or "coining" the strip between embossing rolls. Both processes are "cold-forming", and the embossed material will have less ductility than the virgin metal before embossing. For the minimum bending radius:thickness ratio of embossed metals, consult supplier's data sheet.

Special care should be taken if bending is required in more than one direction. For example, embossed aluminum may be roll formed to one direction without cracking, but it cannot be curved or swaged in the other direction without cracking, unless it is locally or fully annealed after forming into the first direction.

9.2.7 Discontinued Bend Lines

All designers understand the importance of bend lines, but the significance of discontinued bend lines is frequently overlooked. The following examples will highlight the loss of strength due to discontinued bend lines.

1. A manufacturer of building panels produced a variety of sidings and other panels, including "acoustical" panels. In the case of the sound-absorbing acoustical decks, the webs of the panels were perforated but the bend lines and horizontal elements were not. One customer inquired about the strength of a virtually identical panel made from fully perforated material. Tests proved that the acoustical deck with perforated webs had a loss of strength of 3% compared with a nonperforated deck, while the fully perforated panel, having holes at the bend lines, lost 70% of its original strength.

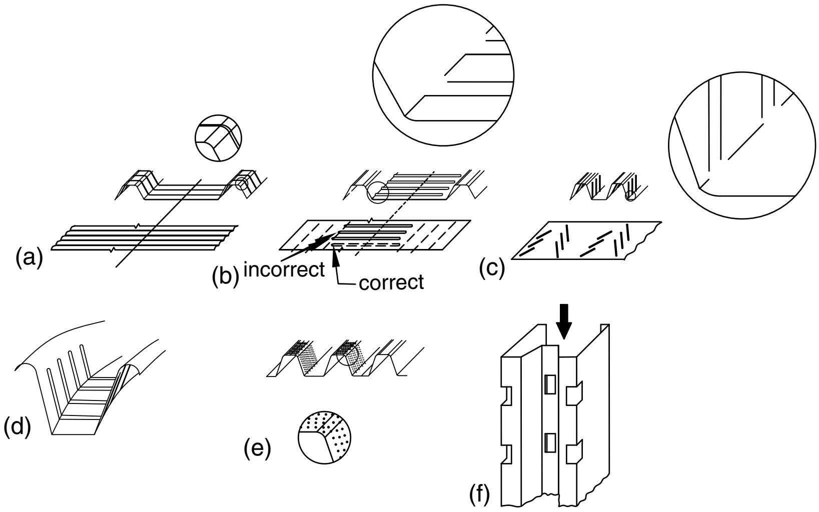


FIGURE 9.7 Discontinued bend lines can drastically reduce the strength of the product.

2. A manufacturer of arched panel buildings had a series of unexpected snow load failures. Panel testing revealed a 40% reduction in load carrying capacity, although the cross section and material was the same as the previously tested, full strength, prototype panel. The only source of weakness could have come from the bend lines. The 7.5-in. (190-mm) deep panel was curved by embossing the inside and the webs (see Figure 9.7d). During curving, the extension of the embossments distorted the originally straight bend lines.

After making a minor modification to the embossing (curving) die, assuring straight bend lines, the original strength of the section was restored.

The strength of a section, after buckling under the maximum load, can be 80 to 90% less than before buckling, even if it is straightened out. These examples demonstrate that bend lines discontinued by prebuckling them with cross corrugation, dimples, or piercing and notching, will reduce the strength of the section, and should therefore be avoided.

9.2.8 Width of Flat Elements

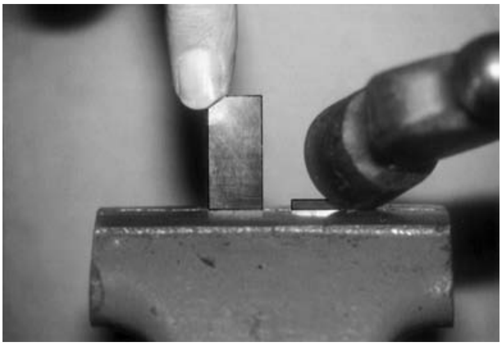
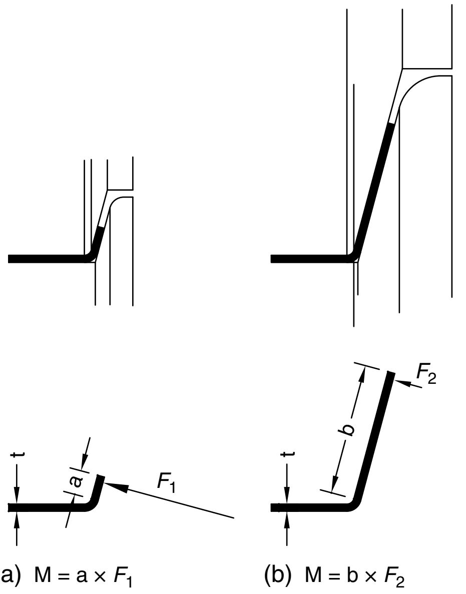


FIGURE 9.8 Bending force is influenced by the leg length.

The minimum and maximum width of the flat elements between bend lines and between the first bend line and strip edge, have practical limitations. The minimum width of the flat elements from the edge to the first bend line is restricted by the forming technology and force required for forming. Figure 9.8 demonstrates the force required to make a 90° bend on two pieces of strapping band, clamped in a vise, with one band sticking out about 1 in. or (25 mm) and the other one about 1/16 in. (1.5 mm). Similarly, during roll forming, excessive force is required to bend short lips. During the earliest stages of the forming, the horizontal components of the force may push the strip back between the rolls, and the lip may not be formed at all. Strip width–tolerance fluctuation and camber make it more difficult to maintain an even and small lip. Although it is possible to roll form smaller lips (e.g., two times the material thickness), it is advisable not to design components with lips shorter than four to six times the material thickness (Figure 9.9).



(a) $M = a \times F_1$ (b) $M = b \times F_2$

FIGURE 9.9 To bend small "lips" require larger forces (F_1) than to bend long legs (F_2).

The maximum width of the flat elements between the edge of the strip and the first bend line is restricted by its effective load carrying capacity under compression, and by the possibility of "edge waviness." Edge waviness is the result of either the wavy starting material or the excessive strain created during roll forming. During roll forming, the edge of the strip usually travels a longer distance than rest of the strip. In case of a simple U channel (shown on Figure 5.8 and Figure 5.9), the bend line travels in a straight direction, while the edge travels in the shape of a helix. The wider the flat element is, the shorter the distance is in which the forming is accomplished (i.e., less passes or shorter center distance between passes); and the larger the degree of the finished bending is, the more stress will be generated at the edge of the strip. If the stress exceeds the elastic limit, then permanent deformation occurs. It will be very difficult, if not impossible, to compress the elongated material back to its original length after the forming is completed. As a result the excessive permanent strain (increased length) will show up as a wavy edge (as shown on Figure 5.2a).

One way to minimize edge waviness created by either roll forming or wavy starting material is to form additional bend lines close to the edges as shown in Figure 9.1.

Mill edge coils, used to form wide panels, have loose width tolerances (in the magnitude of +3/16 to 0 in., or +5 to 0 mm). It is a good practice to provide sufficient strip edge "runout" in the design. Properly designed runout will not interfere with the assembly of the panels but allows for the utilization of wider coils (see Figure 5.38). Slit edge coils usually have a tight width tolerance (± 0.005 in. or ± 0.13 mm). Tight width tolerance is frequently required to form products with tight tolerances.

Legs, which are either too short or too long, can create assembly or erection problems. Some examples are shown on Figure 9.10. Additional small lips (legs) can eliminate the need for tight width tolerance, thus reducing material cost. At the same time, the added lips usually increase the strength of the section.

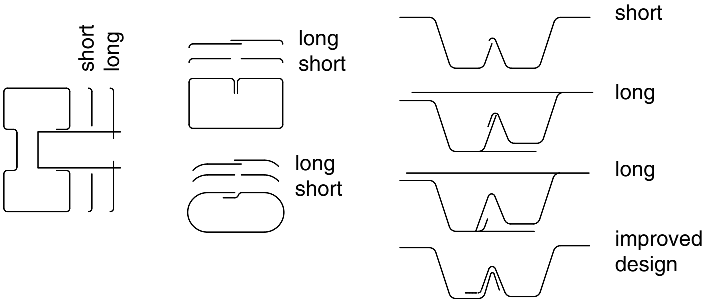


FIGURE 9.10 Clever design can eliminate the need for tight blank width tolerance.

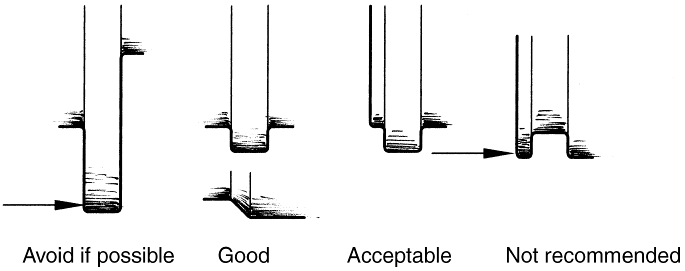


FIGURE 9.11 Thin rolls can easily break.

9.2.9 Stiffener Ribs

As mentioned previously, wide flat sections do not contribute fully to the compressive strength of the section. Therefore, designers, for this or for other functional purposes, frequently incorporate additional bend lines into the products. If these bend lines are too close to each other, then the thin, male roll can easily break during roll forming. The breakage is usually caused by side pressure generated either by uneven material thickness or an uneven gap between rolls (Figure 9.11).

In building panels, garage doors, structural and other components, "stiffener ribs" are frequently added to provide more bend lines. These stiffener ribs are most frequently triangular, trapezoid, round bead, or flat-ribbon shaped (see Figure 9.1). The stiffener ribs either can be "formed-in" or "stretched-in" to the cross section. Formed-in stiffener ribs can have any depth and are fully accounted for during blank size calculation. Stretched-in ribs do not require additional material, but their depth is limited. The depth will depend on the mechanical properties and thickness of the material and their distance from the nearest bend lines. Decorative stiffener ribs, used in building panels, made from low strength, high elongation metals can usually be stretched into a depth of approximately one or two material thicknesses.

Wide, flat elements between bend lines do not present any problems for roll forming, but the appearance of the finished panel may be poor. Most of the commercially available coils are not completely flat, but have either wavy edges or a wavy center. The latter type is referred to as a "full-centered" or "oil canny" surface. These imperfections are induced during the rolling process at the mills and cannot be removed by straighteners. Roll forming can minimize the effect by distributing the ripples, but there is a chance that the "oil canny" effect will be visible in the flat sections wider than 5 to 6 in. (125 to 150 mm), in light gage material. Glossy surface and paint will accentuate this unsightly effect, shown on the left side of the panel on Figure 9.12. The right-hand side of the same panel shows typical grooves or stiffener ribs formed or stretched into the material. Added bend lines will divide the wide flat surface into smaller segments, and will dissipate waviness. Embossing, or the occasionally used cross-embossing, also alleviates the effect of the "oil canning."

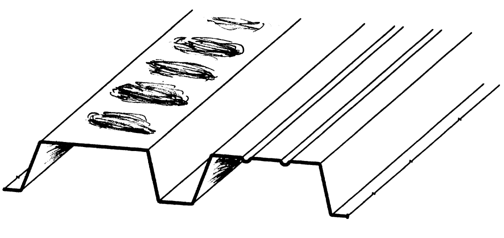


FIGURE 9.12 Added bend lines can minimize the "oil canny" (center-wavy appearance).

The residual stresses across the strip and in the direction of rolling, generated by the "stretched in ribs," will create other deformation (shown on Figure 9.13). Wind can blow away built-up roofing if the adhesive, applied to concave top of roof deck

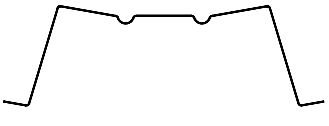


FIGURE 9.13 "Stretched-in" ribs create a cross-bow.

shown on Figure 9.14, is not in contact with the insulating panel above them.

Some types of "cross-bow" deformations can either be eliminated by proper roll design or have no detrimental effect. For example, the large cross-bow on the farm roofing panel held in vertical position in the top of Figure 9.15 will not be apparent after installation, because its own weight will flatten it out when placed on supporting structure in or when fastened to the supports.

For appearance or functional purposes, large, wide, flat surfaces are sometimes specified. After forming of these panels are completed, large elastic stresses in the formed edges will "contract" the flat parts of the panels, thus compressing the centers and creating an oil canny, center-wavy appearance. In these cases, it is even more important to generate only relatively small longitudinal strain during the forming of the edges of wide flat panels.

Experience shows that tension-leveled coils do not provide better, or less wavy, panels. Often slightly edge-wavy starting coils are better starting material for panels with large-flat-center surfaces.

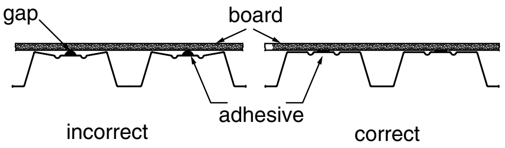


FIGURE 9.14 Built-up roofing can be blown away by wind if adhesive applied to the concave surface is not touching the board above it.

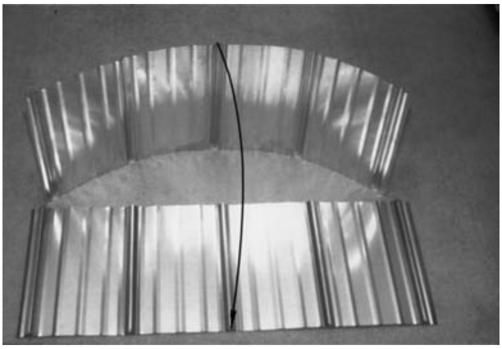


FIGURE 9.15 Cross-bow in farm roofing can be disregarded because the self-weight flattens the panel during installation.

9.3 Secondary Operations

9.3.1 Operations in the Line

A large percentage of roll formed products undergoes additional operations before erection, assembly or use. These secondary operations include: piercing, notching, lancing, louvering, stitching, mitering, slitting, cutting to length, joining with other materials, embossing, bending across roll forming, curving, marking, coining, welding, coating, bonding, in-line foaming, painting, caulking, interleafing, packaging, and others. Because its productivity, the aim is to incorporate as many secondary operations in the line as possible, assuming that it can be economically justified. In every case it is important that product design should match available manufacturing technology and vice versa.

9.3.2 Punching

Table 9.2 to Table 9.6 indicate how a simple "U" channel with three pairs of holes in its web can be manufactured by roll forming, punching, and cutting to length in the 17 different ways.

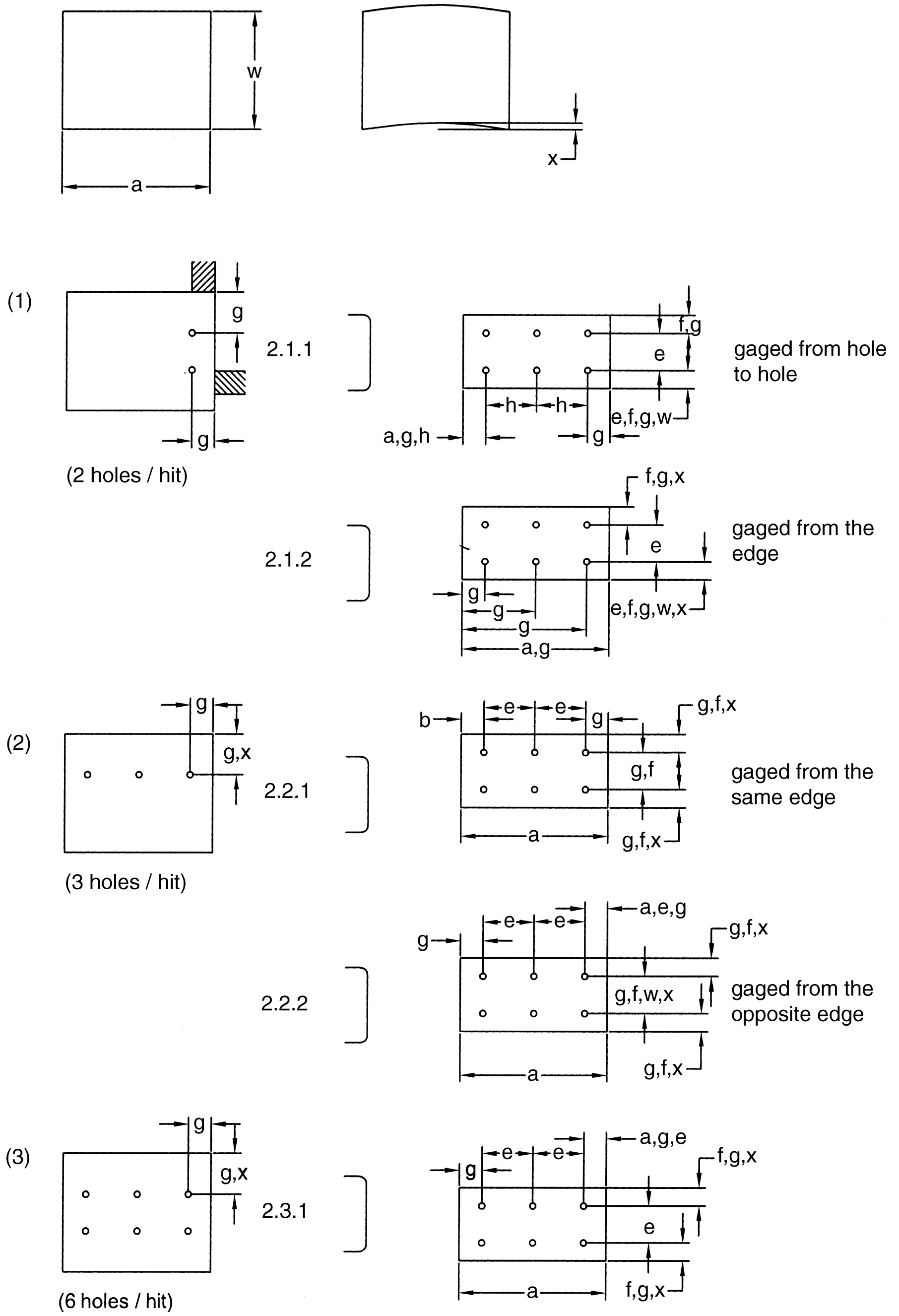
The above examples show that the location of holes, tolerances from bend lines, and tolerances from the end of the channel will depend on the selected manufacturing technology. The more complex the design is, and the more methods of manufacturing that are possible, the more important it is that the designer should be familiar with the manufacturing process.

The following additional precautions should be considered when holes are incorporated in roll formed sections.

9.3.2.1 Strip Edge-to-Hole Distance

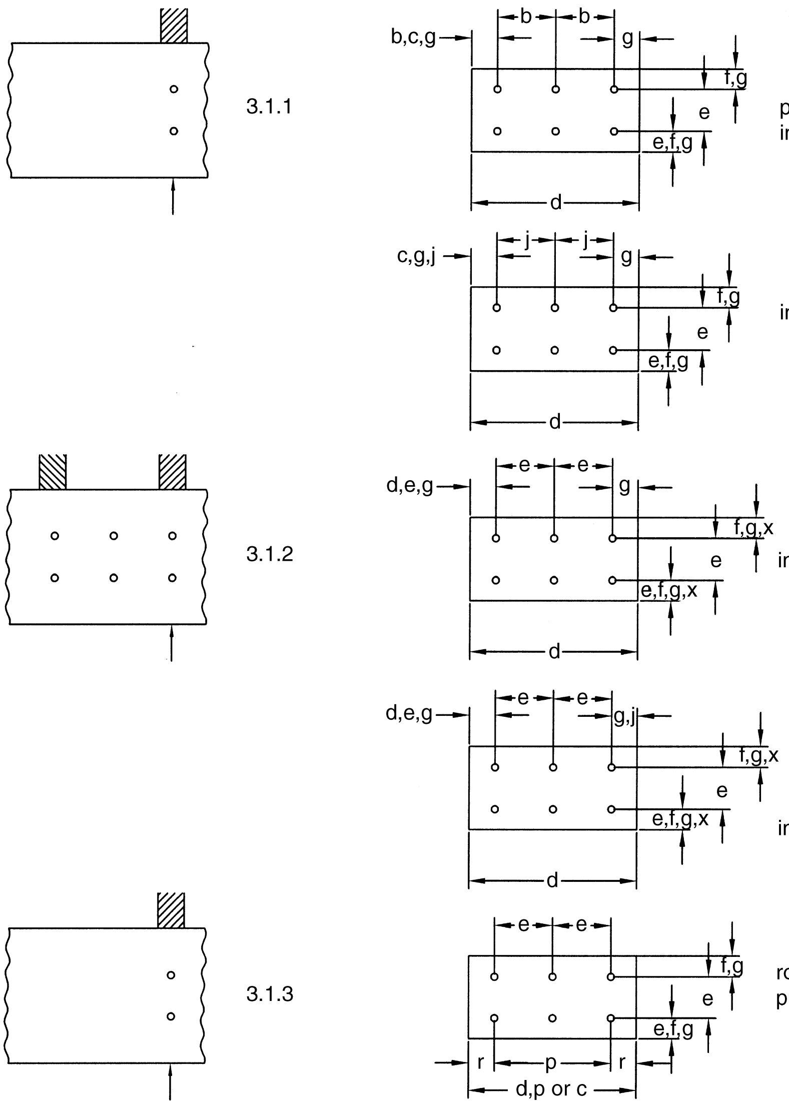
Excessive deformation of holes can occur as a result of stretching and compressing segments of the roll formed sections. Examples are shown on Figure 9.16.

TABLE 9.2 "U" Channel Made from Precut Strip



Deformation of holes can be minimized or completely avoided by increasing the width of the material between the hole and the coil edge, forming the section more gradually with more passes, using larger diameter, smoother "lead-in" rolls, not applying excessive pressure on the strip edges, and minimizing the increase of the pass line roll diameters from pass to pass.

TABLE 9.3 "U" Channel Made from Continuous Prepunched Strip



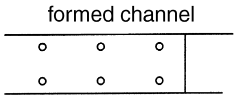
9.3.2.2 Hole-to-Hole Distance in Longitudinal Direction

Frequently, the finished products will be longer than the starting strip. The hole distances in the longitudinal direction, prepunched to specific dimensions, can increase during roll forming (Figure 9.17). The "stretch" in a longitudinal direction can be minimized by: forming the section gently (using more passes), using proper setup (not "pinching" the material between rolls), minimizing or eliminating the usual pass-by-pass roll diameter increases, and keeping a tighter control on material thickness, mechanical properties and camber.

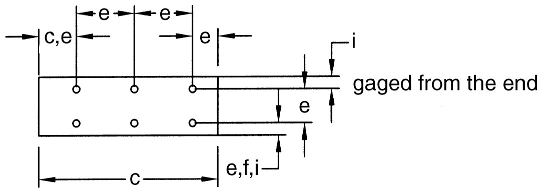
In some unusual cases (such as many bend lines in thicker materials, or restricting the flow of material at the exit side of the mill by mandrels), the length of the finished product can be somewhat shorter than the starting material. This will result in reduced hole distances along the product.

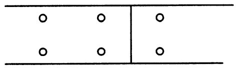
Before completing a prepunching die with multiple punches, the anticipated stretch can be tested by roll forming test strips, prepunched with a preliminary, single hit die, by laser cutting, or other methods.

TABLE 9.4 Roll Formed "U" Channel Punched and Cut after Forming in the Line



6 holes and cut to length / 1 hit





6 holes and cut to length / 1 hit

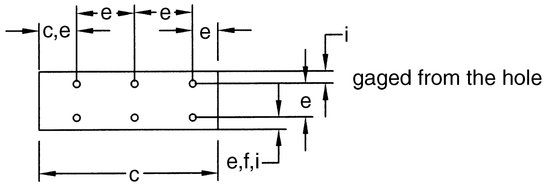
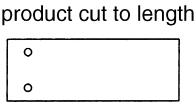
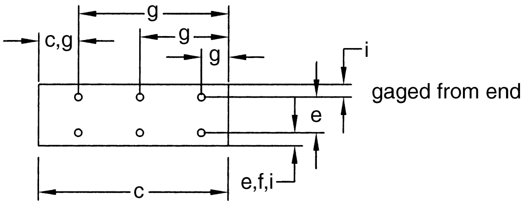
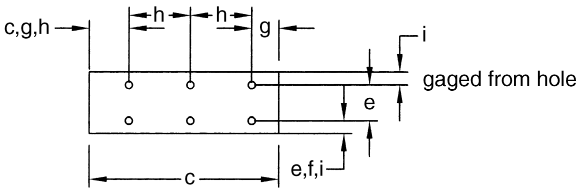


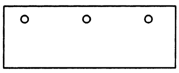
TABLE 9.5 "U" Channel Punched after Cutting (Separate Operation)



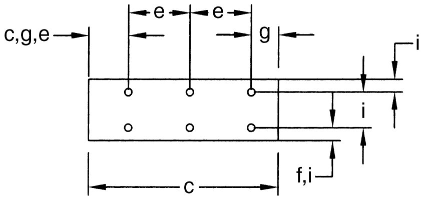
(2 holes / hit)

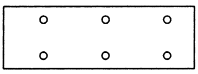






(3 holes / hit)





(6 holes / hit)

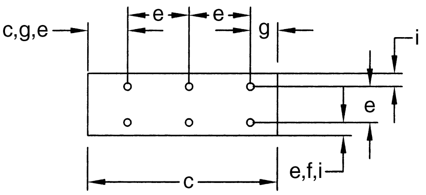
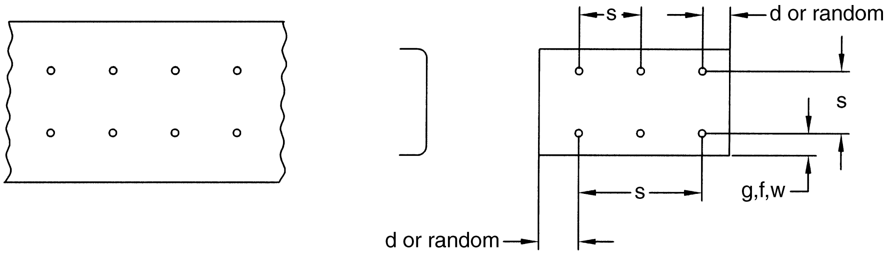


TABLE 9.6 Rotary Prepunched



In spite of all precautions, it will be a difficult task for the operator to keep the "stretch" uniform thus keeping the hole centers to tight tolerances. For example, excessive roll pressure created by incorrect setup or significant increase in strip thickness can increase a 100-in. (2500-mm) long section by 1 to 1.25 in. (25 to 32 mm), thus increasing the distance between prepunched holes.

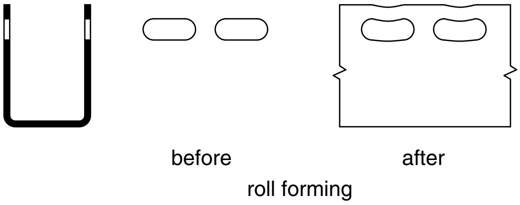


FIGURE 9.16 Holes close to the strip edges may deform.

9.3.2.3 Hole Shape

In addition to the deformation caused by the "stretching-compressing" described above, the elongation of finished products may change the shape of the hole (see Figure 9.18). Holes close to the bending line can be deformed by stresses across the direction of roll forming as shown on Figure 9.19.

It is difficult to form "lips" shorter than 4 to 6 times material thickness. Short lips between punched holes and bend lines may not be bent to the same degree as the longer segments (Figure 9.20).

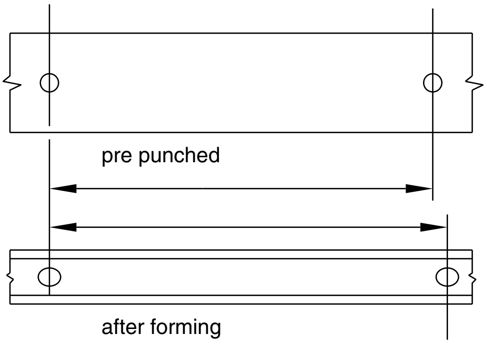


FIGURE 9.17 Hole center distances can increase in the direction of roll forming.

9.3.2.4 Hole-to-Cut-Edge Distance

The minimum hole-to-cut-edge distance will depend on the method of punching.

In the case of rotary piercing and cutting product to length, the cut may be made at any position, without considering the hole locations. However, using the pick-up type of die positioning, the hole-to-cut-edge distance can be made uniform, but the product length tolerance will be influenced by the accuracy of the hole locations.

If holes are prepunched and the location of cutting is determined by a positive pick-up pin entering into the hole, then the hole-to-cut-edge

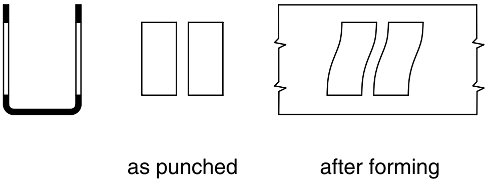


FIGURE 9.18 Hole shape can change during roll forming.

distance is established by the mechanical means. If there is only one hole close to the cut edge, then the size of the pick-up pin may influence the distance. If the pick-up pin enters another hole further away from the location of the cut, then the minimum distance may be influenced by the stiffness of the product. Buckling between the hole and the cut edge can result in loose tolerances.

If the punch is incorporated into the cutoff die, then the minimum distance will be dictated by the minimum die blade thickness, which is required to prevent breakage and to provide maintenance free operation.

9.3.2.5 Postpunched Hole-to-Bend-Line Distance

When holes are punched after forming, then the distance between the hole and bend lines is frequently dictated by the space required for punch or die.

If the "legs" are facing up (see Figure 9.21), then the hole-to-bend-line distance is restricted by the safe clearance that the punch can enter between the legs, and by the minimum flat area required for the die to support the section. The same figure shows the condition when the legs are down. In this case, the minimum distance is restricted by the minimum wall thickness of the die to fit between the downward legs of the products. In special cases, the die can be made to the same profile as the roll formed section that will be punched (as shown on Figure 9.22).

9.3.2.6 Direction of Burr

The "slug" generated during punching must be disposed. Therefore, the punch is usually placed above and the die underneath the section. Otherwise, slugs remaining on the surface of the products can damage the rolls or other dies.

For the above reason, burr is usually directed downward. If one surface of a product must be "burr free," then the roll designer usually forms the legs of the products in the predetermined direction. For example, to keep the surface of shelves free of burr, the punch must enter from the top; therefore, the legs of the shelves must be formed downward. An alternative method is to squeeze the burr back to the flat surface during roll forming.

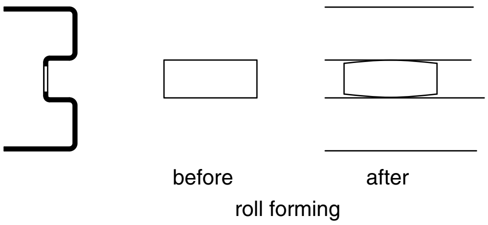


FIGURE 9.19 Holes too close to the bending line may deform.

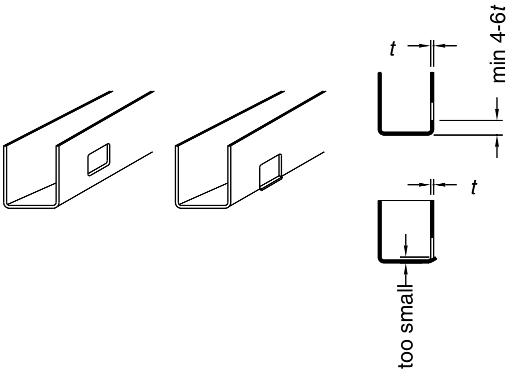


FIGURE 9.20 Edge of holes should be at least 4 to 6*t* distance from the bend line.

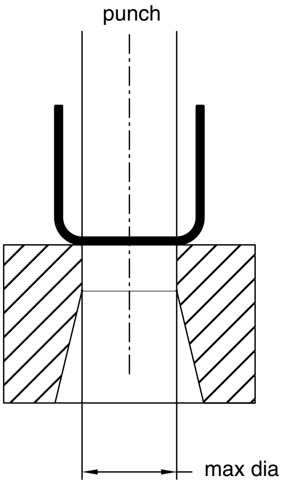


FIGURE 9.21 Clearance between the punch and product determines the maximum hole size when punched with "legs up."

9.3.3 Rotary Punching

The distances between the holes punched by a properly designed rotary unit are uniform and are within a tight tolerance. However, changing (adjusting) the distance between the holes is a difficult and complex procedure.

9.3.4 Notching

Discontinued edges have a tendency to flare. To minimize the flare, more passes are usually required. Among other factors, the flare will depend on how deep the notch is (Figure 5.31). Notching also requires a prepiercing press and, in most end-notch cases, a double shear cutoff die. Notching of the edges makes the welding or lock seaming of strip edges of closed sections difficult or often impossible. However, when the end of the product does not have a simple, straight cut, then it is usually easier to prenotch the parts before roll forming. In some cases, prenotching is the only practical way to produce the part (Figure 4.34 and Figure 9.23).

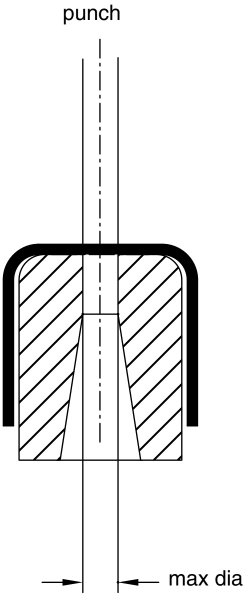


FIGURE 9.22 Die size restricts hole diameter if "legs" are facing down.

9.3.5 Lancing, Partial Punching, Louvering, and Embossing

In these four processes, a formed section of the product will protrude out from the flat strip.

Lancing usually refers to a product feature that is cut around a substantial part of the protrusion and it is bent out of the original plane in a straight line (Figure 4.44 and Figure 4.45).

Partial punching refers to a procedure that is similar to normal punching, except that the "slug" remains attached to the parent strip and it can be removed later on with a little force. It is similar to the "knock-out" holes punched into electrical boxes.

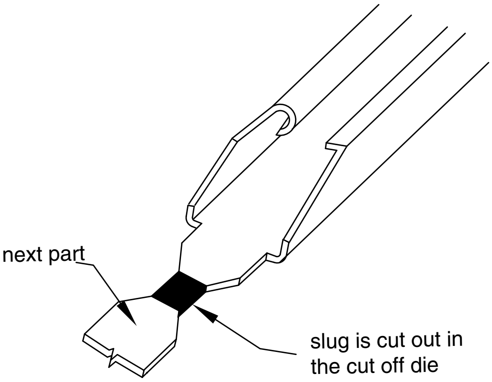


FIGURE 9.23 In some cases, the ends of the formed parts must be prenotched to facilitate cutting to length.

Louvering is similar to lancing, but the bend line where the "louver" joins the strip is usually longer and often has bent elements (Figure 4.46).

Embossing usually refers to a procedure where the material is drawn out from the original plane without discontinuing the strip (Figure 4.49).

If lancing, partial punching, louvering, or embossing is completed before or during roll forming, then the roll designer must provide openings in the rolls for the protruding parts to avoid crashing them back to flat. Similarly, the protrusions must pass through the cutoff die, which may result in a longer cutoff die stroke or a small distortion at the cut end.

Providing space for the protruding parts in the nonhorizontal part of the roll formed section may require a wide roll gap. This gap can cause a usually insignificant change in the angle of the finished part or in the accuracy of the bending radius (Figure 5.151).

9.3.6 Mitering

Mitering is frequently done on parts bent at angles such as picture frames, door frames (Figure 4.36), and window frames. Applying prepunching/prenotching to obtain the proper miter is sometimes complex, but it has great advantages in the subsequent bending/assembly operations.

9.3.7 Slitting

Slitting the edges of the strip during or at the end of the roll forming operation is rarely performed process, but extremely seldom it can be useful if very accurate edge tolerances are required. Edge slitting has been used to align edges before high frequency welding of previously corrugated sections (e.g., helical culvert pipes).

Center slitting is used when two products are made side-by-side from a double width strip. In this latter case, the product is slit in the middle or at the end of the forming process (Figure 9.24). Forming two pieces side-by-side increases productivity and can be useful when the same number of left- and right-hand parts are required.

9.3.8 Cut-to-Length

The cut-to-length process is described in Chapter 4. The designer must take the capability of the existing roll forming line into consideration unless the company purchases new and better length sensor, die accelerator, new press, or a complete new line to suit the tighter length tolerance. While section dimensions and tolerances can be influenced by the roll design, length tolerance is mainly the function of the equipment.

9.3.9 Joining Different Materials

Different types of materials can be joined in the roll forming process. The difference can be in thickness, mechanical properties, and type of material. Different types of steel, stainless steel, aluminum, plastic, rubber, and other materials can be joined in the process.

The joining of different materials can be accomplished by mechanic means (such as stitching, clinching, or crimping), resistance, or any other type of welding, adhesive bonding, foaming, extrusion (such as extruding rubber or plastic on a roll formed section), brazing, soldering, and other ways (Figure 5.28, Figure 4.132 to Figure 4.137). Knowing these possibilities, the designer may come up with a better product, but must be aware of the restrictions. Restrictions can be in the process speed, cutting to length, or forming the parent material after joining with another material.

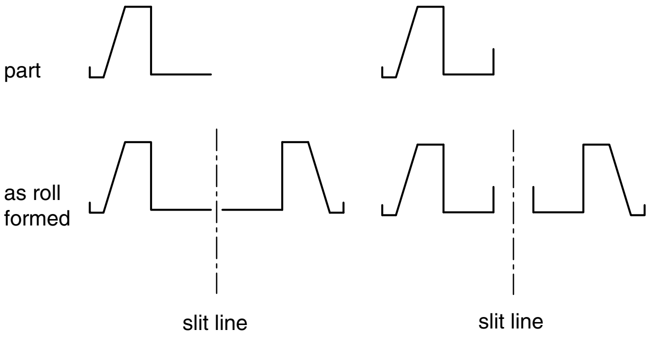


FIGURE 9.24 Two parts roll formed from one common coil can be parted (slit) before the first forming pass, in between, or after the last roll forming pass.

9.3.10 Bending across the Rolling Direction

Although roll forming is usually associated with bending the metal at bend lines parallel to the direction of roll forming, it is possible to bend the finished section at 90° or at other angle to the direction of rolling. A typical example is the shorter ends of a metal shelf. The shorter ends can be bent in the line at 90° to the direction of roll forming after the forming of the longitudinal stiffener elements at the two edges. This bending can be accomplished in a separate operation, after cutting to length, with an end (wing) bender (Figure 4.47, Figure 4.50 to Figure 4.54) or with another roll forming mill running at 90° (Figure 4.48 and Figure 4.49) to the direction of the first mill. Alternatively, the continuously made parts can be cut off and the ends bent 90° in one hit in the cutoff die.

9.3.11 Roll Forming Nonparallel or Nonstraight Bend Lines

With special equipment or arrangement, it is possible to roll form sections with nonparallel bend lines. A typical example is the pie-shaped roof sheets of grain storage bins (Figure 9.25). Special equipment can be used to roll form edge ribs on a curved "orange peel" segment of the silo roof.

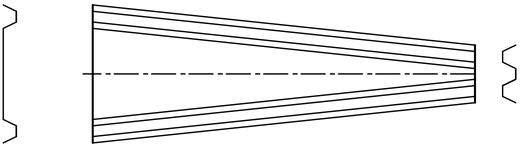


FIGURE 9.25 Special process is used to roll form nonparallel ribs.

9.3.12 Curving and Sweeping

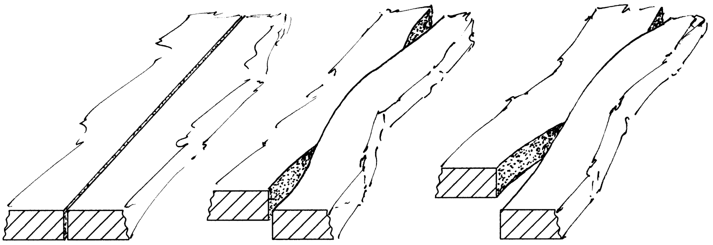
This process is described in details in Chapter 4. The product designer must consider the minimum curving (sweeping) radius for each cross section, material, and thickness. Minor design variations such as bending radius, stiffeners and others can influence the minimum curving radius. Hole locations and cut-outs can influence the curving radius or may require special tooling.

9.3.13 Coining

Coining, or reducing the thickness, is not a typical roll forming operation, but occasionally it is required. It requires more force to make the material thinner than to form it. Therefore, the right equipment (proper shaft diameters, bearings, drives etc.) must be available for the process.

9.3.14 Marking

Products can be marked in various ways such as stamping, embossing, laser marking, inking or painting, labeling and others. Mechanical marking, such as stamping and embossing can be included in



(a) good (b) bad (c) very bad

FIGURE 9.26 Wavy edges reduce the quality of the weld.

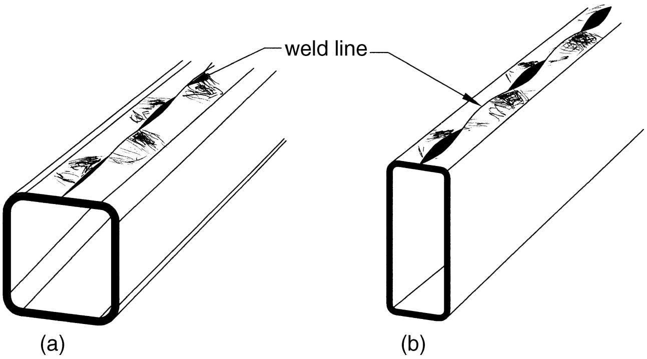


FIGURE 9.27 The edges of deeper sections (b) will be wavier than shallow sections (a) unless more passes and longer center distances are used.

the cutoff or prepunching press or performed by rotary markers. Marking with presses places the mark in a specific location while rotary marking usually places the marks in a line at uniform distance from each other, but not at a specified distance from the cut ends.

9.3.15 Welding, Brazing, and Soldering

These continuous processes can be incorporated into the continuous roll forming process. Noncontinuous resistance welding or arc welding at discrete position can be accomplished after cutting to length although “flying” guns may be applicable in certain cases. Welding requires properly matched surfaces or edges, waviness in one or both surfaces will create problems (Figure 9.26). The deeper the section is, the more passes and longer horizontal pass distances are required; otherwise, significant edge waviness cab be experienced (Figure 9.27). If possible, for the same cross section, it is preferable to weld on the longer side (Figure 9.28).

For welds where the edge alignment is critical, additional bend lines adjacent to the weld (Figure 9.29a) will eliminate or minimize edge waviness. In other cases, for example, for arc welding, edge forming (shown in Figure 9.29b) is suggested. In both cases, the additional bend lines will increase the strength of the section.

However, in many continuous welding processes, a discontinuity, such as a prepunched hole (Figure 9.30) can create a major problem.

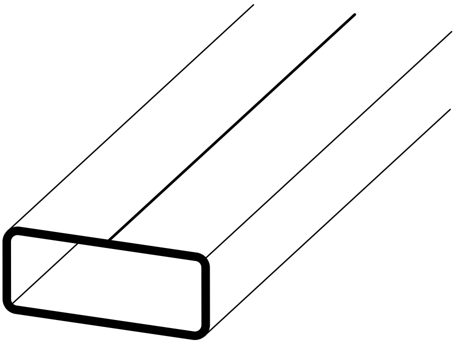


FIGURE 9.28 It is better to roll form a section (like one shown in Figure 9.27) with the weld line on the longer side.

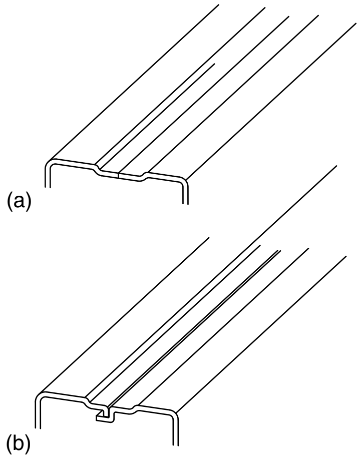


FIGURE 9.29 Additional bend liens reduce edge waviness.

In these cases, relocating the weld line away from the prepunched holes can be the right solution (Figure 9.31).

9.3.16 Coating

Owing to the difference in process speeds, coating lines are very seldom incorporated into roll forming lines, with the exception of plastic/rubber extrusion. However, painting individual roll formed parts or assemblies are frequent. The foresight of the designer can help the subsequent coating processes. Holes for hooks to hang the product can be incorporated in the design. Other prepunched holes for drainage and other features facilitate the metallic or nonmetallic coating process.

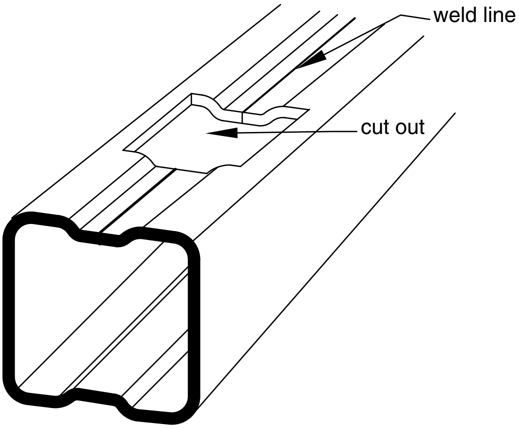


FIGURE 9.30 Prepunched holes, notches can create welding problems.

9.3.17 Adhesive Bonding, Caulking, and Foaming

The method of adhesive application can influence the product design. In the production line both adhesive and caulking material is usually applied from the top. To apply foam into the individual pieces or assembled products, such as insulated doors, an appropriate opening has to be provided in the product. For continuous foam application, such as insulated wall panels, the design of the join can be critical. During foaming, considerable inside pressure develops. The designer has to know how the large flat panels will be supported against "bulging out" during the foaming process.

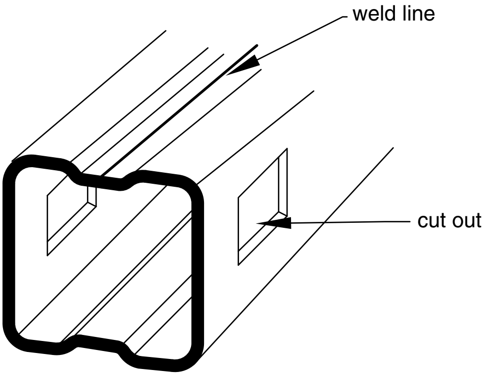


FIGURE 9.31 Designing product with the weld seam away from holes simplifies welding.

9.4 Profiles Manufactured in Different Sizes

9.4.1 Spiral Pipes, Panels, and "U" Channels

To meet different load or other requirements economically, the designer frequently has the option to select from similar shapes formed from different thickness of metal or made to a variety of sizes. The tooling cost to manufacture a profile in more than one size varies from practically nothing to the cost of a full set of tooling for each size.

The designer of the roll formed profile greatly influences the tooling and production costs by specifying the correct, variable dimensions before tool design starts. For example, different diameters of corrugated spiral pipes can be produced with the same tooling by simply changing the entry angle of the strip (Figure 4.95).

A 36-in. (914.4-mm) wide building profile can be converted to 35.43 in. (900 mm) metric coverage with minimum extra tooling cost if the rolls are split at the right place and an insert prepared when the roll set is made.

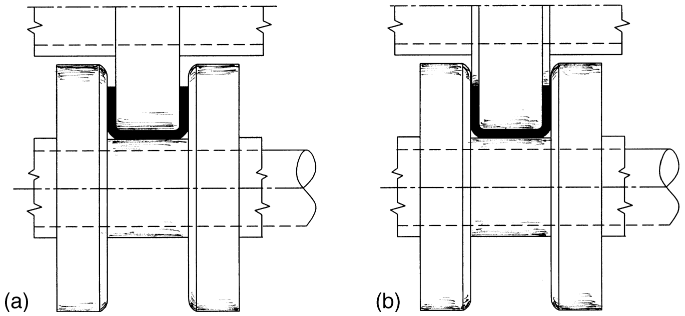


FIGURE 9.32 The tolerance on leg length is affected by the roll design.

Using the conventionally designed rolls shown on Figure 9.32, the length of the legs of the "U" channels can be varied within a certain limit, just by varying the blank size. If for tight tolerances, the legs are "trapped" (or registered) in the rolls, the length of the legs cannot be changed but leg length tolerances will be much tighter (Figure 9.32b).

9.4.2 "C" Channels and "Z" Sections

In the case of "C" channels, which are basically "U" channels with legs bent inwards, the above-mentioned change cannot be achieved as simply when traditional roll forming line with shafts supported at both ends is used. The inward facing legs of the "C" channels are usually formed in the early passes, restricting size changes in the subsequent passes. However, both "U" and "C" channels can be reasonably easily manufactured in multiple widths within specified limits by changing the position of rolls (see dimension "H" in Figure 9.33). Frequently both types of "C" and "Z" sections are rolled with one combination set of rolls. However, in conventional mills changing the "W" dimension often requires a complete set of tooling for each size when standard mill is used.

Special purpose, quick change, duplex roll forming mills have been developed specifically for this purpose. With these mills, unlimited varieties of "C" channels can be manufactured between the specified maximum and minimum web widths, leg heights, and lip lengths without tool change. The changeover time from one dimension to another can be as short as 1 to 3 minutes.

The forming of a "C" channel is a symmetrical process, bending both legs upwards. The rolling of a "Z" section is an asymmetrical process because one edge of the strip is forced up and the other one down during forming. The forcing of one leg up and the other down induces asymmetrical stresses into the finished "Z" section. The result is a twist in the finished product. To eliminate or minimize this "twist" and to keep the edge of the strip at about the same height, roll designers prefer to shape the "Z" section at an angle as shown in Figure 5.45.

The forming of the "Z" section at an angle does not lend itself to width (web length) adjustments and each section size require a separate set of rolls. Therefore, this method is usually used only when large run quantities are required.

However, a variety of special quick changeover "duplex" mills are available to roll form both the "C" and "Z" sections with different web, leg, and lip dimensions.

9.4.3 Building Panels

In the case of ribbed (corrugated) building panels, adding (or removing) two ribs will keep the section symmetrical; only the width of the starting material has to be changed. Adding (or removing) one rib to the width may create minor asymmetry problems and makes roll forming with the same set of tooling somewhat more difficult.

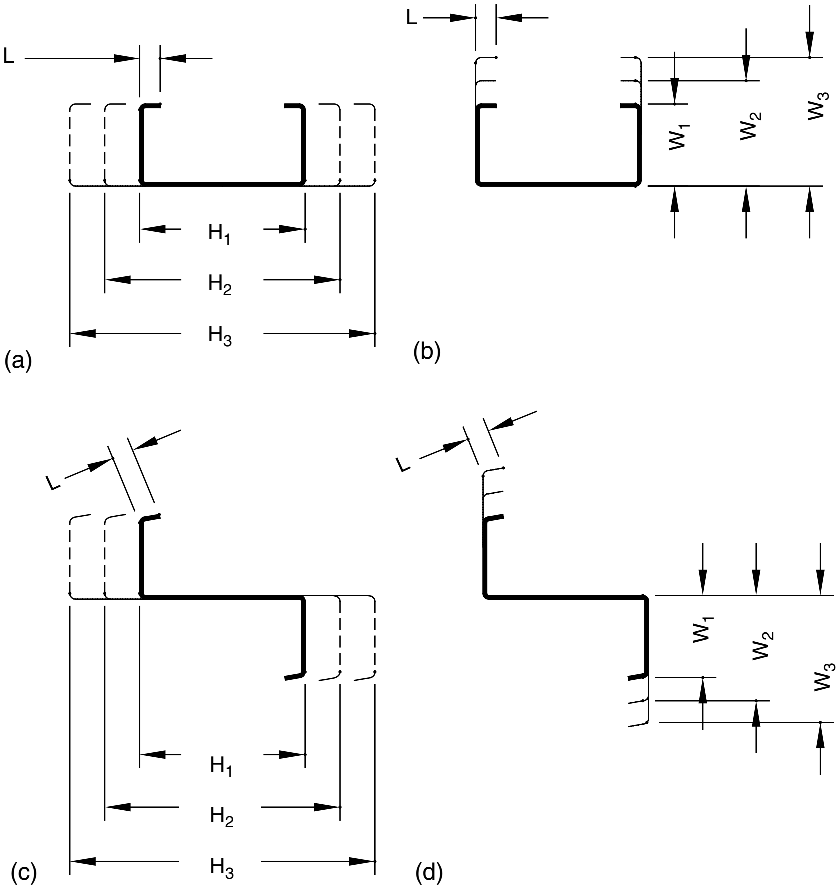


FIGURE 9.33 Changing the "H", "L", and "W" dimensions is a slow process in standard mills but it takes only minutes in special mills.

When only the panel (product) edges are roll formed, quick changeover duplex mills can produce panels with any width within the maximum-minimum limitations of the mill.

9.5 Design of Specific Products

Because of its high productivity and versatility, roll forming is used to manufacture almost every type of product. Several articles about roll forming automotive, appliance, building, grain storage bin, storage, and other products are published in the technical magazines and conference proceedings.

9.6 Dimensioning and Tolerancing

9.6.1 Dimensioning

After a product is designed, the idea has to be communicated to the manufacturing plant. The communication is usually in the form of drawings. For roll formed sheet metal products, national or international drafting standards are not available. As a result, a large percentage of the drawings are inefficiently, inadequately or incorrectly dimensioned and toleranced. Sometimes, companies establish their own guidelines for dimensioning and tolerancing. However, dimensioning and tolerancing methods are usually more influenced by the design software and individual habits than by established standards.

A dimension is "a numerical value expressed in appropriate units of measure and indicated on a drawing and in other documents along with lines, symbols, notes to define the size or geometric characteristics, or both, of a part or a part feature" [421].

Basic dimension can be defined as "a numerical value used to describe the theoretically exact size, profile, orientation, or location of a feature or datum target. It is the basis from which permissible variations are established by tolerances on other dimensions in notes or in feature control frames" [420].

Product designers and draft persons frequently employ dimensions to suit their own habit, company's standard, or available space on the drawing. Although it is important, product dimensioning frequently does not provide information in a format that is required for manufacturing, strength calculations or tool design. For these purposes, additional calculations are usually required; these can be time consuming and the source of errors.

To calculate the sectional properties (strength), blank size (strip width) and to design tools, the section usually is divided into straight and curved elements. For the straight elements, the length, and for curved elements, the bending radius to the inside of the profile and the formed angle are required.

These dimensioning methods, however, are not suitable and are not used for dimensioning roll formed products. For manufacturing purposes, especially to locate additional features such as holes, notches and dimples, a different method of dimensioning is required. It is recommended that the ASME Y14.5M "Dimensioning and Tolerancing" standard [421] be used as a guideline.

The application of the ASME standard for roll formed products should follow the guidelines described below:

- During roll forming, products are usually "wrapped" around the male die. Therefore, in most cases, it is preferable to show inside dimensions as shown in Figure 9.34.

  The final decision on applying dimensions will be influenced by the method of forming, accepted industrial standards, or application. For example, tubular products (which are not completely formed around a male die) are frequently defined by the outside dimension (OD). The

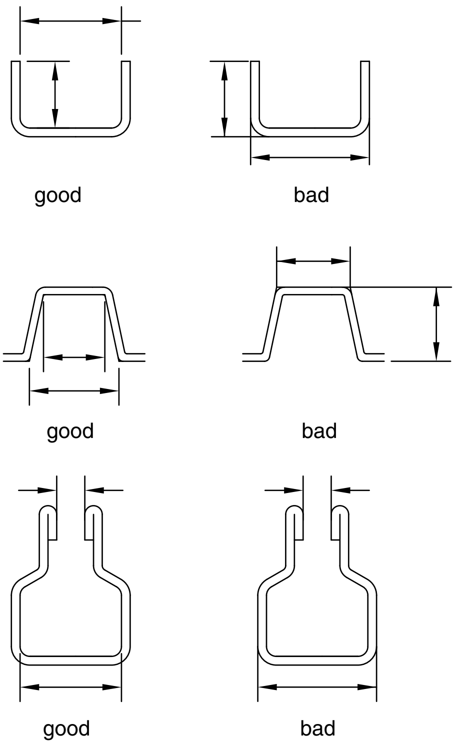


FIGURE 9.34 Dimensioning of the inside surface is preferred.

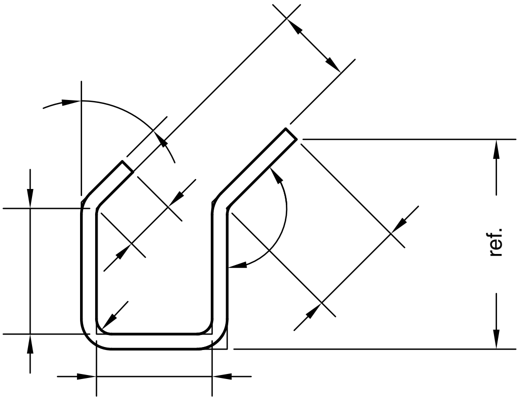


FIGURE 9.35 Tangent point dimensions have been preferred by manual roll designers.

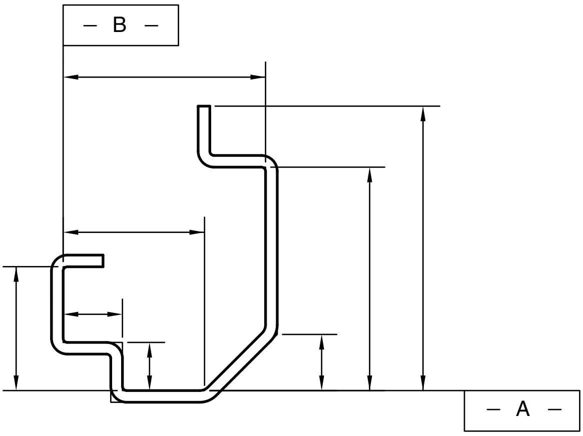


FIGURE 9.36 Base line dimensioning is not used for roll formed product.

outside dimension may also be noted on the drawing if the part must fit into the inside of another component.

- Owing to variation in material thickness, it is preferable to use the same product surface for dimensioning.
- In most cases, it is preferred to dimension roll formed components to the intersect points rather than to the center, or to the starting point of the radius. The distances between the intersect points and the enclosed angle can be used for dimensioning, but may lead to mistakes and errors (Figure 9.35).
- So-called "base line" dimensioning is rarely used to define roll formed sections (Figure 9.36).

9.6.2 Tolerancing

Tolerance can be defined as the total amount by which a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits. In other words, tolerancing specifies the total permissible variation in the size of a dimension and it basically describes the difference between the limits of size.

"Bilateral tolerance" is a tolerance that is expressed as plus and minus values to denote permissible variations in both directions from the specific size.

"Unilateral tolerance" is a tolerance that applies only in one direction from the specified size, so that the tolerance in the other direction will be zero (for explanation, see Figure 9.37).

"Standard tolerances" for manufacturing plants can be achieved at standard production rates, at specified costs, without much extra precaution. Therefore, changing or modifying the equipment or tooling can influence these established tolerances. "Standard tolerances," however, can be specified by government, industry, or other trade standards. To manufacture

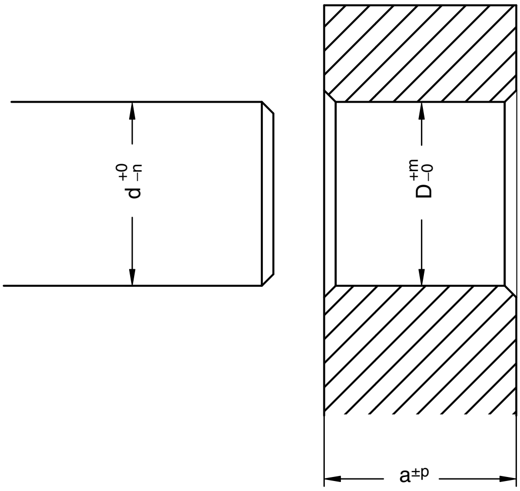


FIGURE 9.37 Bilateral and unilateral tolerances on drawings.

products within these "standard tolerances" the manufacturer must have the right quality equipment, tooling and properly trained personnel.

Tolerances applied to roll formed parts can be assigned into five groups.

- Length and related tolerances
- Tolerances on section dimensions
- Tolerance on deviation from straightness
- Tolerances applied to other features such as holes, dimples, and so on
- Other tolerances such as burr, appearance, and so on.

9.6.3 Length and Cutting Tolerances

The length tolerance of parts made from precut blanks depends on the accuracy of the precutting process but roll pressure, roll design and other factors can alter the precut length.

If the part is cut to length in the roll forming line, then the most critical factors influencing the length tolerance are the type and condition of the cutoff press, the method of die accelerating and length measuring. The length tolerance will be also influenced by the speed of roll forming, roll forming tooling, shape of the product, lubrication, location of holes, skill of operator, temperature, and a few other factors [223]. Therefore, the part designer should realize that the length tolerance depends on the capability of the line used to produce the part at optimum speed. If the part length tolerance must be tighter than the line capability, than either the line has to be run slower, or parts of the line (e.g., die accelerator) has to be replaced, or a completely new line, capable of producing parts within the specified tolerance, has to be acquired.

Squareness of the cut end is seldom specified because it is expected that deviation from perpendicularity of the cutoff die to the direction of roll forming is usually better than normally required. There are cases, however, especially in wide panels, where the inaccurate mounting of die rails or location of the press or other factors will create an "off squareness" problem.

Off square cuts are occasionally specified, such as in the case of gable ends or tapered or curved products. In these cases, the angular tolerance should be specified on the drawing.

9.6.4 Section Dimension Tolerances

ASME Y14.5M or other national standards and the previously mentioned examples provide a guideline for the tolerancing of roll formed profiles. A few additional examples are shown in Figure 9.38.

Figure 9.39a and Figure 9.39b show panels with multiple cells. Both the cell center distance (pitch) and the coverage have a tolerance.

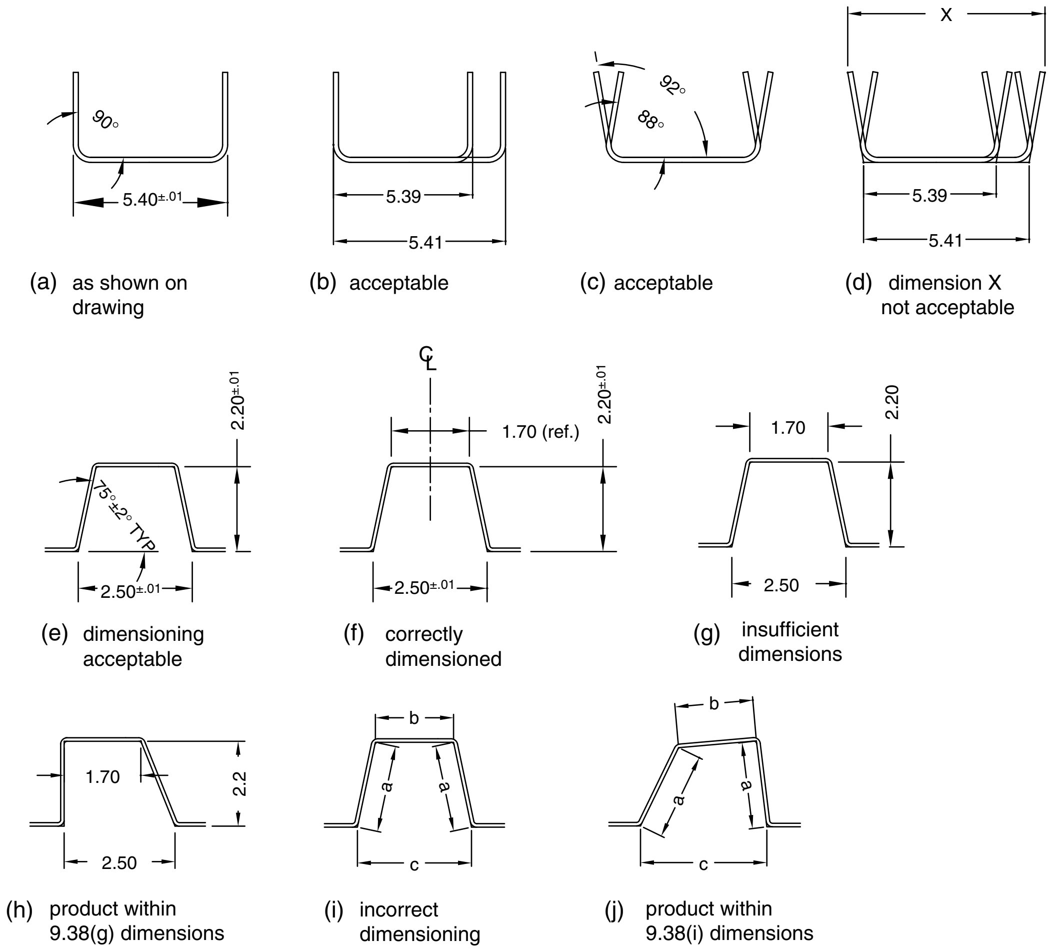
Under other conditions, the accumulated stacked tolerance is calculated as

$$t_{\text{acc}} = \sqrt{t_1^2 + t_2^2 + t_3^2 + \cdots + t_n^2}$$

In the case of roll forming, however, the tolerance on coverage is not necessarily the mathematical function of the accumulated tolerances of the cells. According to the interpretation used by the industry, any cell-to-cell distance should be within the specified tolerance, but the tolerance of the overall coverage is independently specified. Figure 9.39 shows a different way of dimensioning the cell distance, coinciding with the most frequently used method to measure cell distances. The tolerance of cell distance, however, should not be incompatible with the dimensions and tolerances shown on the section drawing.

The dimensions and tolerances on the cross section of a "U" channel shown on Figure 9.40 will also be affected by the manufacturing method, tools and equipment. The dimensions will be influenced by the factors shown in Table 9.7.

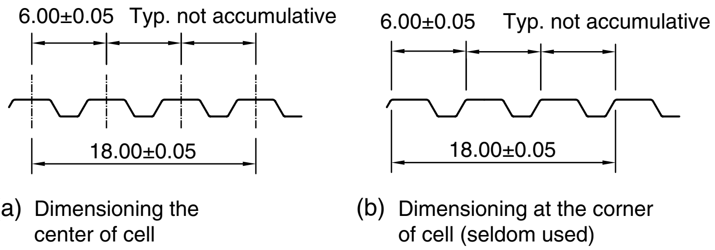
During roll forming, the material is "wrapped around" the male roll. Because the inside dimension (a_{i}) cannot be changed (unless the roll is split), the outside dimension will usually be affected by changes in the material thickness. For example, a 0.078-in. (2-mm) thick steel may have a commercial thickness



(a) as shown on drawing
(b) acceptable
(c) acceptable
(d) dimension X not acceptable
(e) dimensioning acceptable
(f) correctly dimensioned
(g) insufficient dimensions
(h) product within 9.38(g) dimensions
(i) incorrect dimensioning
(j) product within 9.38(i) dimensions

FIGURE 9.38 Interpretation of tolerances.

tolerance of ± 0.005 in. (0.13 mm). If the inside "U" channel is 1.0 in. (25.4 mm), then as a result of changes in material thickness, the outside dimension fluctuates between 0.990 and 1.010 in. (29.14 and 29.66 mm). This fluctuation will be in addition to the tolerance required for forming, springback, set up variations, tool wear, and so on. Therefore, it is not correct to specify, for example, a ± 0.004 in. (± 0.1 mm) tolerance on the outside dimension (a_o) when the two thicknesses of the material alone require a tolerance of ± 0.010 in. (± 0.26 mm). Even a restricted thickness tolerance of ± 0.002 in. (± 0.05 mm) will require a ± 0.004 in. (± 0.1 mm) tolerance for thickness variation, plus all the


6.00±0.05 Typ. not accumulative
18.00±0.05
6.00±0.05 Typ. not accumulative
18.00±0.05

(a) Dimensioning the center of cell
(b) Dimensioning at the corner of cell (seldom used)

FIGURE 9.39 Typical dimensioning of building panel cells.

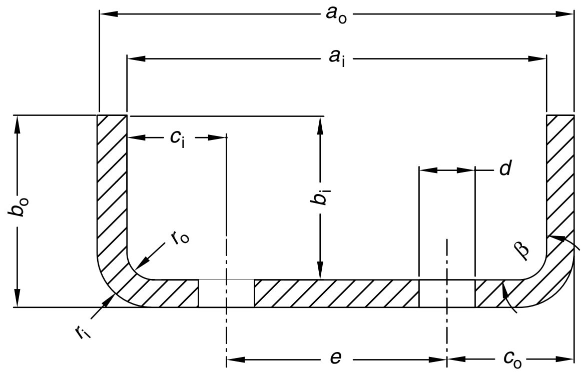


FIGURE 9.40 Dimensioning cross section of a "U" channel.

additional tolerances mentioned above. One must remember, however, that an extra price must be paid for restricted thickness and width or other tolerances.

9.6.5 Deviation from Straightness and Flatness

Products, which are within the specified cross-sectional tolerances, are not necessarily acceptable unless they are within the required straightness and flatness tolerances.

Longitudinal bow, cross bow, twist and flare (see Figure 4.1 and Figure 10.38c–l) should be specified to be tested on a flat surface, with one end of the product firmly held down against a horizontal surface. Longitudinal bow is occasionally checked against a straight edge or two products are held against each other with bows facing each other.

Some standards specify the maximum height of waviness and, occasionally, the minimum distance of peaks from each other but in most cases edge or center waviness, ripples, and herringbone effects are checked and judged visually.

9.6.6 Tolerances Applied to Other Features (Curvatures, Holes, Notches, Embossments, etc.)

In case of curved (swept) products, either the radius, the apex (height of the center of the product above a straight line between the ends), or a deviation from a curved template is specified with appropriate tolerances. The sweep number used by the automotive industry is usually transferred into a checking template or fixture.

It is recommended that each drawing indicates these tolerances and often the method of measuring them, or refers to a company standard.

TABLE 9.7 Factors Influencing Dimensions in Figure 9.40

Dimension	Influenced by
a_i (preferred)	Tooling, springback, flare, height of leg, and dimension β
a_o (avoid)	Same as above, plus variation in material thickness
b_i (preferred)	Tooling, tolerance on strip width, movement of coil, camber
b_o (avoid)	As b_i plus twice the variation in material thickness
c_i (preferred)	Method of piercing, gaging, camber, and so on
c_o (avoid)	As c_i plus variation in material thickness
e (preferred)	Method piercing and gaging
r_i (preferred)	Tooling and springback
r_o (avoid)	Tooling, springback and variation in material thickness
β	Springback and tooling

Dimensioning and tolerancing of holes, notches, embossings, and other features may follow the ANSI 514.5M Standard. The importance of how the dimensions and tolerances are applied is demonstrated in Table 9.2 to Table 9.6 on a simple roll formed "U" channel with six holes on the web.

The application of dimensioning in these examples shows how the manufacturing method and tooling affects the way of dimensioning and tolerancing. These examples also illustrate how the manufacturing personnel are directed to select technology, equipment, tooling, production speed, material, and inspection gages by the occasionally arbitrary selected application of dimensioning and tolerancing.

The "U" channel shown in the above-mentioned tables could be manufactured by forming precut blanks or cutting the product after roll forming. The holes can be pierced individually or by two, three, or six at a time, prior to, during, or after forming. The tables show the correlation between manufacturing methods, dimensioning and tolerancing. Manufacturing processes based on piercing one hole at a time or forming the channel in a press are not included in the tables.

Tolerance will be influenced by:

"*a*": Length tolerance of precut line
"*b*": Length tolerance of prepiercing press
"*c*": Length tolerance of roll forming line
"*d*": Length tolerance of roll forming line (with pick-up mechanism)
"*e*": Punch position in die set
"*f*": Forming tolerance
"*g*": Gaging from cut edge
"*h*": Gaging from hole
"*i*": Gaging from formed edge
"*j*": Accuracy of strip feeder

"*p*": Uniform but accumulating, tolerances of "*e*"
"*r*": Dimension "*r*" is either random or related to dimension "*e*" tolerance if the first case is not applicable, in the second case, it depends on the accuracy of the cutoff die equipped with pick-up pin.
"*w*": width tolerance (slitting)
"*x*": camber of blank
"*y*": camber of formed product

The top illustration in Table 9.2 shows the manufacturing process where the "U" channel is roll formed from precut sheets or strips having a camber. When two adjacent holes in the web are pierced in one hit, the location of the two holes from the edge is usually set by gaging the piece at the end. The location of the other pair of holes can be set by gaging the holes from the pierced holes or from additional end gages. The tolerance in the longitudinal direction will depend on the method of the gaging. During piercing, the strip is usually pushed against one longitudinal edge; therefore, the holes in the blank will follow the curvature of the precut strip.

During roll forming, however, the forming rolls will straighten out the section and the holes will be an even distance from the formed corners.

When three holes are pierced at a time, the tolerance of the first hole from the edge will depend on the accuracy of end gauging, but the tolerance between the three holes will be very tight. If the second row of three holes is gaged from the same side of the strip, then the tolerance between the two rows of holes will be better, but if it is gaged from the opposite side, then the strip width tolerance has to be added to the tolerance between the rows of holes. The holes will be in one line in the precut blank but after roll forming they will be out of line as much as the starting strip bowed.

If six holes are pierced at the same time, then the relative location of the holes to each other can be kept at a very tight tolerance. They will be out of line again (the center hole will be closer or further from the formed corner) by the amount of bow in the starting strip.

Table 9.3 shows the effect of the manufacturing process on the piercing tolerance when two or six holes are pierced in a tight line (with flying die), or in a loose line (using a strip feeder and stationary die), with loop between press and roll forming line, when the holes are prepierced.

Table 9.4 shows the different possibilities of punching the holes and cutting the product to length in the line, after forming.

Table 9.5 shows the possibilities of piercing two, three or six holes at a time after cutting the formed channel to lengths.

Table 9.6 is based on rotary punching of strip before roll forming.

The examples above show that there are 17 different ways, with 17 different groups of tolerances, to pierce and form such a simple product. Additional holes and notches and different shapes can complicate the issue further. Therefore, if the designer expects that his or her specifications be followed in the plant, then he or she must apply the dimensions or tolerances in a way that is best suited to the manufacturing method.

9.6.7 Other Tolerances Such as Burr and Appearance

The most difficult is to establish standards for appearance, scratch or other marks, waviness and other characteristic that cannot be measured at the manufacturing plants. Many of these features are judged by eye, influenced by the available light, eyesight, anticipated reaction from a specific customer, or other factors.

In the case of burr, it is important to specify the direction of the burr on the drawings but burr size or other features are seldom specified on the drawings because at most roll forming plants they can be measured only with difficulties or not at all.

9.6.8 Influence of the Applied Tolerances on Cost

The designer's dream is to manufacture everything to exact dimensions or at least to very tight tolerances. Tight tolerances can reduce product cost and simplify assembly. They can also reduce waste material and scrap, and improve the quality of the product.

Manufacturing to tight tolerances, however, usually costs more. It requires more expensive and better quality equipment, better tooling, with more frequent and thorough maintenance. To achieve tight tolerance, the production speed may have to be slowed down, and larger number of products must be checked and possibly scrapped. More precise and expensive measuring instruments and gages are required, operators have to be better trained and the whole organization must be geared to manufacturing products to tight tolerances.

Manufacturing products to loose tolerances, on the other hand may also cost more. Additional material is wasted, assembly and erection costs can increase, and quality, most probably, will be inferior. (for additional comments, see Chapter 4.)

With an increased complexity of shape and hole patterns and other requirements, additional thought should be directed to the method of dimensioning and tolerancing. Properly dimensioned and toleranced product drawings can save from $1000 to $100,000 or more in equipment, tooling, material and manufacturing costs compared with the drawing of identical parts with improper dimensions and tolerances.

Dimensions and tolerances should suit requirements, available equipment, tooling and among others, manufacturing methods. Therefore, it is strongly recommended that the use or reference to the general "machining tolerances" preprinted on the drafting paper is avoided.

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10

Equipment Installation, Roll Setup, Maintenance, and Troubleshooting

10.1 Installation of Roll Forming Lines 10-1
Plant Layout • Service Lines (Electrical, Compressed Air, Water etc.) • Space Requirements Around the Roll Forming Mill • Foundations, Foundation Bolts, and Leveling • Installing Roll Forming Mills • Aligning and Installing Uncoilers • Aligning Presses • Aligning Other Equipment in the Line • Start-Up and Training

10.2 Roll Installation and Setup 10-8
Considerations for Roll Installation • Installing Rolls on the Shaft • Checking Roll Gaps • Setting up Straighteners

10.3 Maintenance and Spare Parts 10-14
Manuals • General, Preventive, Predictive Maintenance Program • Lubrication Program • Lubrication Instruction • Mill Maintenance • Maintenance of Mechanical Presses • Maintenance of Hydraulic and Pneumatic Presses • Maintenance of Other Equipment in the Line • Aligning Mill Shaft Shoulders • Handling and Storing of Rolls and Tools • Spare Parts

10.4 Troubleshooting and Trouble Prevention 10-32
The Root of Troubles • Problems Created by Design and Drawings • Problems Created by the Material • Problems Caused by Equipment • Problems Caused by Tooling • Troubles with the Know-How of the Workforce • Troubleshooting • Trouble Prevention

George T. Halmos
Delta Engineering Inc.

10.1 Installation of Roll Forming Lines

10.1.1 Plant Layout

It is expensive to install a roll forming line and costly to move it; therefore, they generally stay in place for many years or even decades. At that location, during the roll forming operations, thousands of coils are loaded on to the uncoiler and millions of pieces of finished product are transported from the end of the line. To minimize material handling costs, it is essential to have a good plant layout with an efficient flow of material.

To layout the inside of a plant properly, some of the factors listed below (among others) must be considered:

1. Area occupied by the line
2. Space required to operate, maintain, and repair the line safely and comfortably
3. Area required for the incoming material, finished products, and spare parts

The methods of handling coils and finished products are also important considerations. Too much unnecessary space will increase operating costs (indirectly increasing the overhead cost, which includes heating, maintenance, taxes, etc.). On the other hand, too little floor area will restrict the efficiency of the line, and possibly affect the safety of the operators. For additional details, see Chapter 8.

10.1.2 Service Lines (Electrical, Compressed Air, Water, etc.)

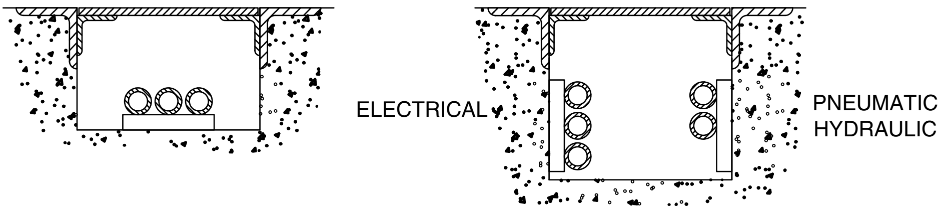
Roll forming lines usually require only electricity and compressed air. Water and drainage are only needed for seldom-used water-cooled brakes or for special equipment such as resistant welders.

Each roll forming line is connected to a main electrical switch box, which contains the main disconnecting switch. The power (industrial voltage to the motors, 110 or 220 volts for controls, lights, etc.) is fed through conduits from the main electrical box to the line. Compressed air is supplied by pipes to the uncoiler, mill, die accelerator, and other equipment.

Installing the conduits and the pipes on the floor is less expensive than to bury them, but they create a safety hazard. They can be covered with formed checkered plates, but this method is not recommended for areas with forklift truck traffic. The best way to prevent a hazardous situation is to install the conduits and the air pipes into trenches, covered with flat checkered plates (Figure 10.1).

Electrical and air connections between the mill, the press and other components, which are not located in the regular walking area, can be made above the floor surface. Air and water lines are occasionally fed directly from the ceiling into the machine, but this method is not practical if cranes are used in that area.

It is very helpful if the supplier of the roll forming line provides a floor layout showing the electrical, air and other requirements well before the installation. A typical example is shown in Figure 10.2. It is prudent to install larger diameter conduits and air pipes than those needed at the time of installing the line. During installation, and sometimes many years afterwards, additional wires have to be pulled through those conduits and more air could be required for the retrofit pneumatic devices.



(a) RECOMMENDED (b) RECOMMENDED

(c) NOT RECOMMENDED (d) AVOID

FIGURE 10.1 Power conduits, compressed air, and hydraulic pipes run in covered trenches.

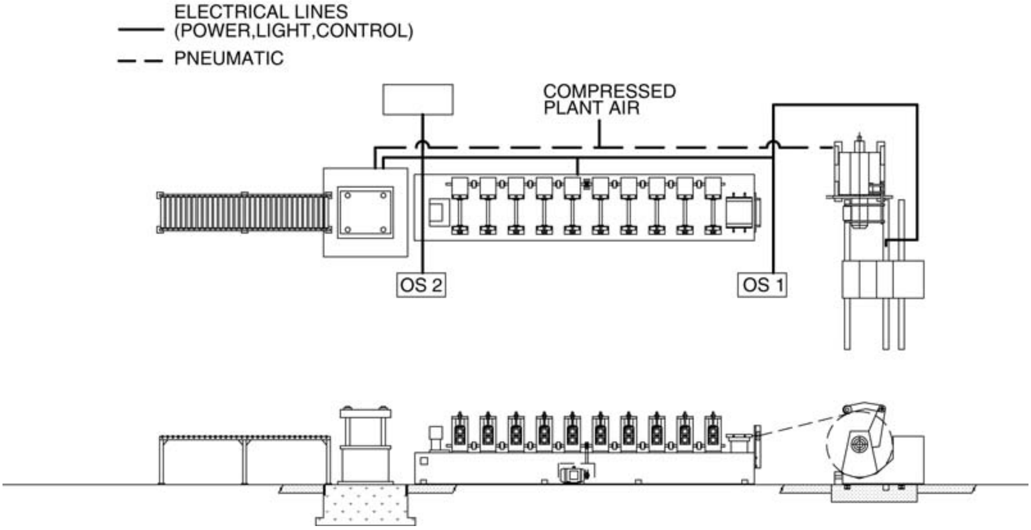


FIGURE 10.2 Typical trench layout for power and air lines.

10.1.3 Space Requirements around the Roll Forming Mill

A roll forming line layout usually shows only the space occupied by the equipment itself, but in a plant layout additional space requirements have to be included to ensure efficient and safe operation.

In the plant layout, the following space requirements should be considered:

- A safe walkway for the operators at the operator side of the line
- Extra working space around the consoles and control panels
- Sufficient space for paperwork (work orders, drawings, etc.)
- An area or a bench for the hand and power tools required for operating/maintaining the line
- A walkway at the back of the line
- A walkway between the equipment to the back of long lines
- Safe distances from electrical switch boxes, as specified by law
- Sufficient space to ensure that the equipment can be maintained and parts can be replaced safely with the aid of the required lifting equipment
- Space for forklift truck traffic
- Space for crane attachments
- Coil storage space at the uncoiler
- Finished products handling, marking, marshaling, and packaging area
- Space for finished product quality control (table, lights, measuring fixtures, floor area to check waviness, etc.)
- Space for the packaging material (tote boxes, lumber, strapping, etc.) for use during production
- Space for scrap and offcuts
- Space to store rolls and roll-storage devices
- Space to store rafts (plates) for other sections
- Space to store cutoff, prepunching, and other dies
- Space to keep the equipment used for the secondary operations that are temporarily removed from the line
- Space for lubricant for forming

The above space requirements are directly related to the roll forming line, but do not include: coil storage, coil upenders, finished product storage, and other common areas specified in the plant layout.

10.1.4 Foundations, Foundation Bolts, and Leveling

Roll forming mills usually do not require a separate foundation if the plant has a reasonably good-quality, 6-in (150-mm) or thicker, reinforced concrete floor. Mechanical and pneumatic presses over 20 to 30 tons (180 to 270 kN) require separate foundation blocks in almost all cases (see Chapter 3). Hydraulic presses usually do not need foundation blocks.

Uncoilers and most of the other equipment in the line do not require separate foundations. However, all equipment needs foundation bolts to tie it to the floor after the line has been aligned.

The equipment manufacturer usually provides an accurate foundation bolt layout and either recommends or supplies the right type and size foundation bolts.

Usually, the centerline of the mill serves as the main datum line for the complete roll forming line. Distances along the datum line and the hole locations perpendicular to that line are marked on the drawings. The datum line position is marked on the floor with a tight string. The hole locations are transferred from the drawing and are marked on the floor.

To compensate for any possible inaccuracies, providing a reasonably large clearance around each pre-installed foundation bolt is recommended (Figure 10.3). This clearance allows for slight bending of the bolts to accommodate the hole location on the equipment. Once the equipment is aligned and leveled and the anchor bolts are tightened, the clearance around the bolts can be filled with concrete.

For units which are not heavy, the expandable type of anchor bolts can be used. After aligning and marking the bolt holes on the floor, the lightweight unit can be moved sideways. Then, the marked holes can be drilled and the expandable anchor plugs inserted. Next, the equipment should be placed back, aligned, leveled again and the bolts tightened to floor.

All equipment is accurately leveled in both directions. Leveling is frequently accomplished with leveling screws installed in the base of the equipment. Plates and shims are often positioned underneath the base plates of presses to support larger surfaces. After being leveled at the ends, long units such as the roll forming mill beds should also be leveled at their center to avoid sagging. Height adjustment is more critical when the ends of two machine parts, such as the split mill beds, must be accurately positioned on the same level. Uncoilers must be accurately leveled.

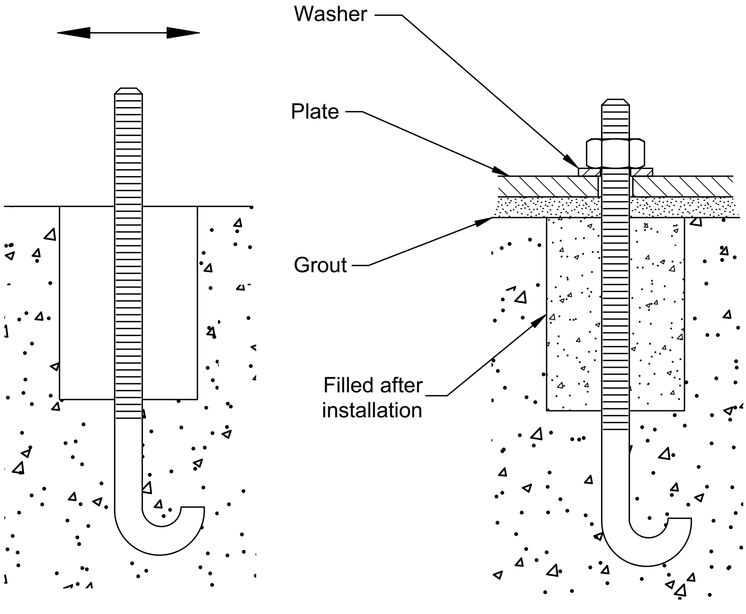


FIGURE 10.3 Clearance around foundation bolts allows adjustment.

10.1.5 Installing Roll Forming Mills

Line installation starts with positioning the roll forming mill. All other equipment is installed to suit the mill. First, the mill is placed on the foundation bolts. If the dimensions of the hole locations on the drawings and the lines transmitted to the floor are the same, then the center line of the roll space in the mill should be exactly above the center line drawn on the floor.

If laser or optical alignment is not available, then using a simple plumb line should be sufficiently accurate. Alignment starts by stretching a steel wire above the center line marked on the floor. The wire is tightened between two solid, nonmoving points outside the two ends of the roll forming line.

The location of the wire at each end can be rechecked with the plumb, just in case the anchor points of the wire move. The best approach is to use two plumbs. If both plumbs are just at the marked center line on the floor, then the wire above is exactly in the right position.

One sleeve placed on the first top shaft and one on the last top shaft of the mill helps the alignment. The sleeves have a notch or a point marked exactly at the halfway point of the roll space. For example, if the roll space is 24 in. (60 mm), then the mark is exactly 12 in. (300 mm) on an approximately 13 in. (330 mm) or longer sleeve. The sleeves are pushed against the shaft shoulders. The two plumbs hanging from the wire are positioned above these marks. The mill is moved sideways, back and forth until the tip of each plumb is positioned exactly at the marks.

At this point, the mill has to be leveled in both directions and the center lines rechecked. When everything is correct, the foundation bolts are tightened and the centering and leveling are checked again. This completes the installation of the mill, which is the first piece of equipment in the line.

10.1.6 Aligning and Installing Uncoilers

The mandrel of the uncoiler must be perpendicular to the center line. In the case of tight lines (lines without a loop between the mill and the uncoiler), the wider the strip, the more critical the perpendicularity. If the uncoiler has a sliding base, then its shoulder, against which the coils are loaded, should be aligned with the shaft shoulders. This means that the tip of the plumb, hanging at the center line of the mill, should be at half roll space distance from the uncoiler backplate. If the uncoiler is not adjustable in the direction of the mandrel axis, then the uncoiler backplate or stop is usually aligned either with the shaft shoulder (Figure 10.4) or, in a single purpose mill, with the entry position of the strip-edge into the rolls (Figure 10.5). This will assure that whenever a coil is loaded onto the uncoiler and is pushed against the backplate or stop, the lead end of the strip enters directly into the rolls. However, if the roll set will be interchanged, then it is still better to align the shoulder of the uncoiler with the shoulder of the mill shaft. A spacer against which the coils are pushed can be installed in front of the backplate. All coils pushed against the spacer will be aligned with the correct entry position in the mill.

If optical or laser alignment is not available, then the perpendicularity of the mandrel can be checked easily with a 8- to 16-ft (2- to 4-m) long rigid bar, firmly attached to the mandrel. The length of the bar depends on how high the wire is above the floor. The bar can be attached to the mandrel by clamps or by tack welding. An adjustable target attached to the far end of the bar should just touch the wire (Figure 10.6).

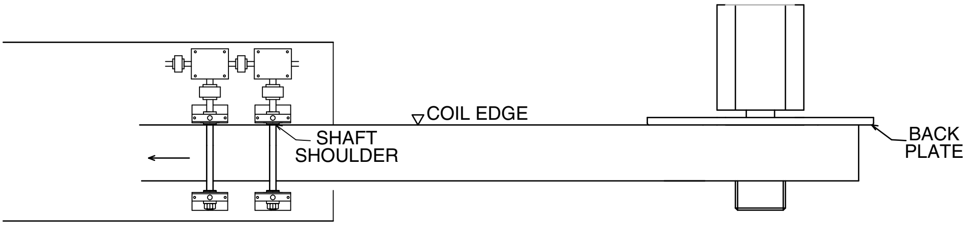


FIGURE 10.4 Uncoiler backplate is aligned with the shaft shoulders.

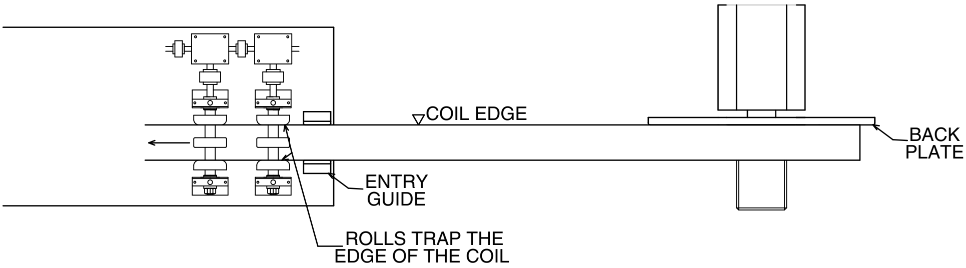


FIGURE 10.5 In a single-purpose mill, the uncoiler backplate may be aligned with the strip edge trapped in the first pass rolls.

When, after about a 90° rotation of the mandrel, the attachment on the bar touches the wire again (as shown in Figure 10.6), the mandrel is exactly perpendicular to the wire. If, after rotation, the bar is not touching or pushing the wire, then the uncoiler is not perpendicular and the direction of the mandrel must be slightly altered. After moving, the first "touching" position has to be established again and the mandrel has to be rotated. This procedure should be repeated until the bar just touches the wire in both positions, which means that the mandrel is perpendicular to the line.

The next step is to level the mandrel, then bolt the uncoiler (or its sliding base) to the floor.

It is highly recommended to install an additional "stop plate" with two to three anchor bolts at one corner of the uncoiler as shown in Figure 10.7. This extra heavy stop plate or angle will reduce the chance of loosing the perpendicularity when the mill "jerks" the uncoiler at every start. This sudden pulling action has the same effect as hammering, and after several hundreds and thousands of starts the mandrel slowly moves and rotates in the direction of the mill (Figure 10.8). This effect is noticeable in approximately 30 to 40% of the installed uncoilers. Mandrel misalignment can create waviness and other problems in the finished products.

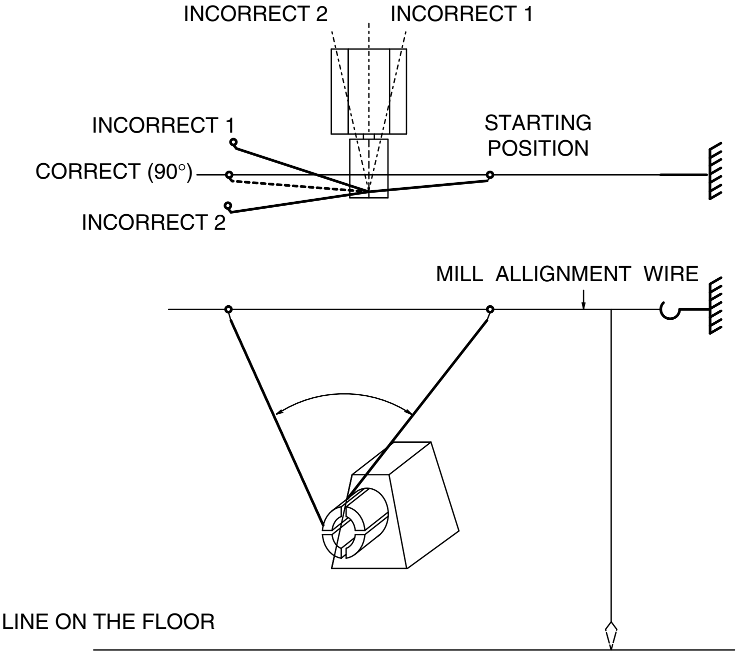


FIGURE 10.6 A simple method to align uncoiler mandrel 90° to the centerline.

10.1.7 Aligning Presses

The centerline of the press must be directly above the centerline marked on the floor. Unfortunately, most press manufacturers do not mark the front-to-back centerline on the presses. Therefore, the centerline has to be measured and marked at both the entry and exit ends of the press. One or two simple templates (Figure 10.9) protruding from the press base can mark the centerline and greatly simplify the alignment with the wire and plumbs. Misaligned presses can create problems, such as sections cut "off square," incorrect hole patterns, waviness, products stuck in the cutoff die, and so on.

When the press is aligned, it must be leveled carefully in all directions and tied to the floor with anchor bolts. If vibration pads are not used, then the press is usually grouted (concrete placed in the gap between the press base and the foundation).

10.1.8 Aligning Other Equipment in the Line

All other equipment in the roll forming line as well as the conveyors and the transfer devices have to be properly aligned, leveled, and fastened to the floor or foundation.

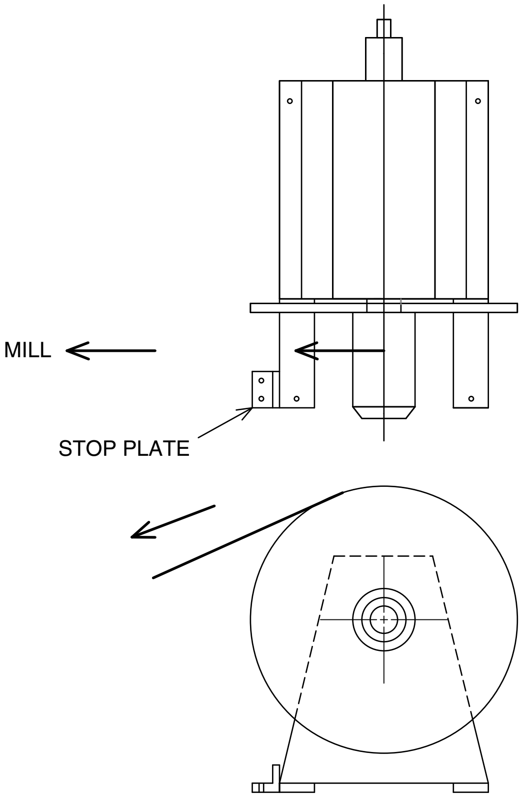


FIGURE 10.7 One additional stop plate can prevent the misalignment of an uncoiler.

10.1.9 Start-Up and Training

After a new line is installed and all service lines (electrical, air, etc.) are connected, the supplier usually checks the installation and starts up the line. In most cases, the start-up commences with the checking of the alignment, the controls and the actions of each piece of equipment. Finally, material is fed through the line and the operations are performed, at first, if possible, at slow speed. When everything is satisfactory, the line speed is increased to its maximum level. This procedure is based on the assumption that the line has already been tested and accepted at the supplier's plant.

In most cases, the operator and the supervisor have already participated in the acceptance test at the supplier's plant and it is assumed that they are already familiar with the operation. However, the in-plant training should be extended to other personnel including: supervisors, maintenance personnel and

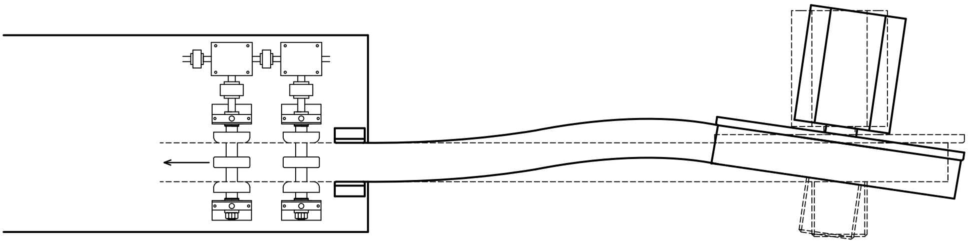


FIGURE 10.8 Constant "jerking" of the strip can dislocate uncoiler from its original position.

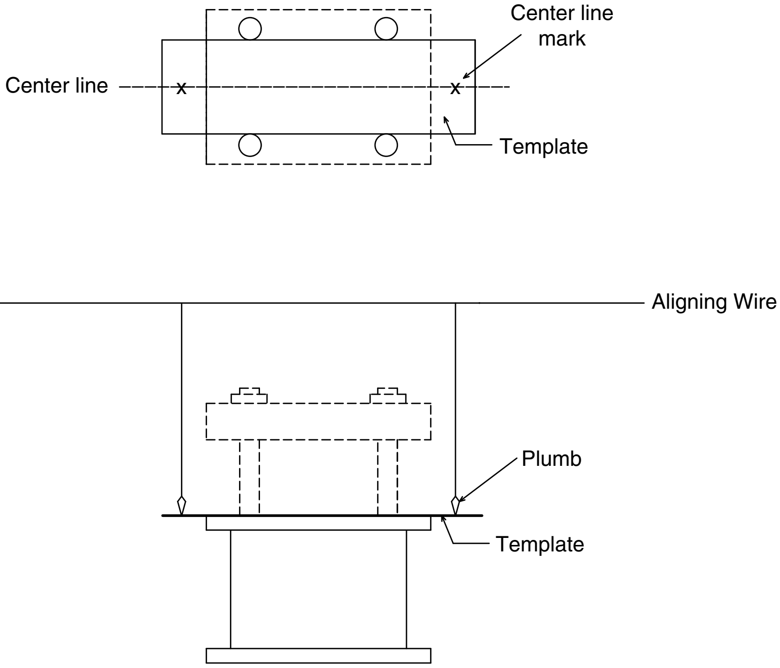


FIGURE 10.9 An aligning template can simplify press alignment with the mill centerline.

additional mill operators. The functions normally carried out by the operators, such as: mill setup, line operation, preparation and application of forming lubricants, daily lubrication of bearings, gears, and so on, basic troubleshooting, and others should be part of this training.

10.2 Roll Installation and Setup

10.2.1 Considerations for Roll Installation

A single set of rolls may contain 10 to 250 rolls and as many spacers. All rolls and spacers have to be installed at the right place, usually with more than 0.001 in. (0.025 mm) accuracy. Each roll and spacer must have the right identification and the operator must have a good "setup chart" in order to place them exactly at the right locations (see Section 5.16 to Section 5.18).

The following additional rules are applicable to most setups:

- The pass numbers marked on the rolls and on the setup charts are usually not the same as the stand numbers on the mill. For example, the rolls of Pass #4 are not necessarily installed on Stand #4 (Figure 10.10).

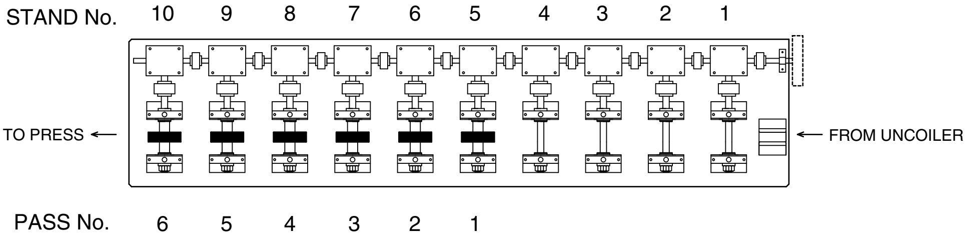


FIGURE 10.10 Last roll pass is installed in the last stand (in this case, Pass #6 is installed in Stand #10).

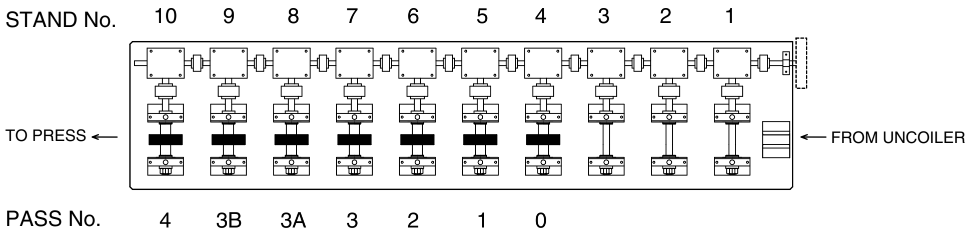


FIGURE 10.11 Some suppliers mark the added or corrected passes as Pass #0 or Pass #3A, #3B and so on.

- It is not unusual that suppliers decide to add additional pass(es) during the roll design and manufacturing stage, or after the initial setup test. As a result, some setup charts may show “0” (zero) or “3A” and “3B,” or “3” and “3A” pass numbers (Figure 10.11) instead of 1, 2, 3, 4, and so on.
- Side-rolls are sometimes assigned with a pass number; for example, Pass #1, Pass #2, Pass #3, Pass #4, Side-Roll Pass #5, Pass #6, and so on. This can mean that side-roll Pass #5 is mounted between two stands, one holding Pass #4, and the other one #6 rolls (Figure 10.12).

  In some cases, side-roll stands are not numbered, or the side-roll Pass #5 mentioned above is designated as Pass #4A and it is placed between Pass #4 and Pass #5. Because side-roll passes are forming the sections, it is recommended that they are given a sequential pass number (as mentioned in the previous paragraph).
- Regardless of how the rolls are numbered, the highest (last) pass number is placed on the last stand, which is closest to the exit side of the mill.

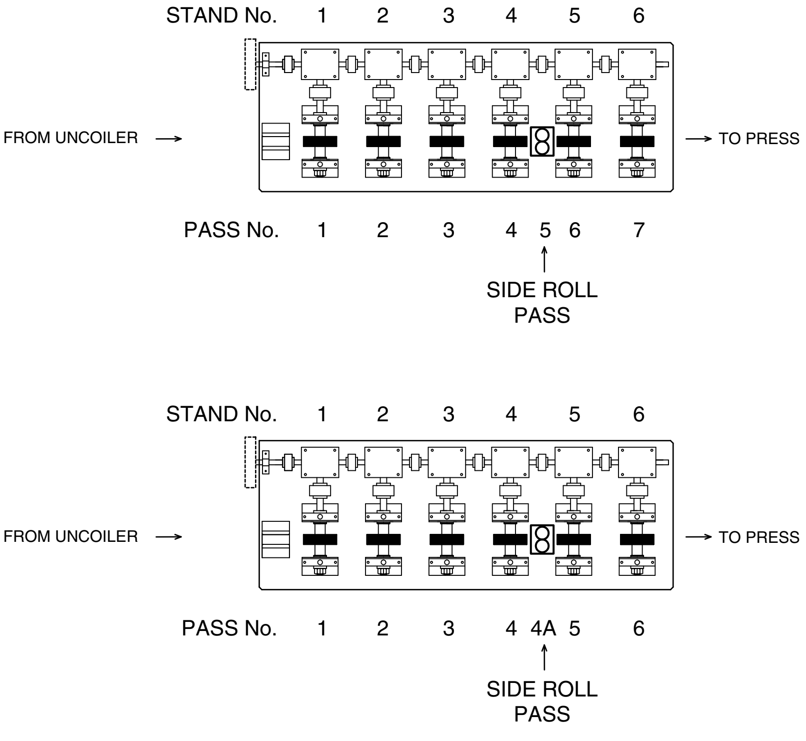


FIGURE 10.12 Side-roll pass may have its own pass number (like #5 in the upper drawing) or a letter designation (like #4A in the lower drawing).

- The method of marking the rolls is described in Chapter 5. The unwritten rule is that the first identification number designates the pass number and the letter “T” or “B” stands for “top” or “bottom” shafts. The next number denotes the sequence of rolls from the shaft shoulder. For example, 3T4 means 3rd pass, top shaft, 4th roll from the drive side, and 12B8 represents 12th pass, bottom shaft, 8th roll from the drive side.
- It is an unwritten but widely accepted standard that on each shaft, the first roll (Roll #1) or spacer is installed first and is pushed to the “drive” side, against the shaft shoulder. The last roll or spacer shown on the setup chart (with the highest number) is closest to the operator.

  Some suppliers include the spacers in the roll numbering system. This means that the first spacer located on the drive side is #1. Other suppliers incorrectly mark the drive-side spacer as “IN” and the operator-side spacer as “OUT” or they just mark the length of the spacer.
- The very thin shims have no designated numbers and they are not marked. These shims are identified by their thickness on the setup chart.
- In the case of “multipurpose” rolls, the roll numbers (sequence) can be mixed up. These rolls must be installed in the sequence shown on the setup charts (Figure 10.13).
- If a side-roll is made out of segments, these should be installed on the side-roll stand shaft according to the roll setup chart (Figure 10.14).

10.2.2 Installing Rolls on the Shaft

The following procedures are applicable to conventional (standard) mills with shafts supported at both ends. However, some of the principles are applicable to all types of roll forming mills.

- Remove the left- and right-hand nuts from the top and bottom shafts.
- Remove the bolts that fasten the outboard stands on the base.
- Pull out the outboard stands and slide them sideways on the mill bed (if there is sufficient space)
- Check the shafts as described in Section 10.3.5 “Mill Maintenance.” Clean each shaft; pay special attention to removing dirt, grit, and grease accumulated at the shoulder.
- Lubricate the shafts lightly.
- Both flat faces of each roll and spacer must be wiped carefully to remove all dirt or grit. All roll markings should face the operator unless otherwise stated on the setup chart. Most rolls are marked in a recessed groove on the flat surface facing the operator. However, roll manufacturers sometimes make the mistake of marking the wrong face of the rolls, or sometimes the rolls are for multipurpose use. In these cases, marks may appear on both faces.
- In most cases, the roll diameters will dictate the sequence of roll installation between the top and bottom rolls (Figure 10.15).
- If a roll is very thin (short), then it may get stuck (wedged) on the shafts, unless it is pushed with its face exactly perpendicular to the shaft axis. The perpendicularity and ease of installation can be achieved by pulling a previously installed spacer or roll back against the side of the thin roll; then both pieces can be pushed together until they are in the right position (Figure 10.16).
- A good “clicking” sound usually indicates that the roll is fully pushed against the shoulder, or a previously installed roll or spacer.
- All rolls and spacers must be keyed to the shafts. Rolls without keys will rotate on the shaft and will ruin its surface. Spacers without keys will also rotate and rub against the surface of the rolls. Owing to constant movement, rubbing against the adjacent roll, their length will be reduced by wear in a short period of time. If the formed material has an abrasive surface, then the spacer not only gets shorter but it may also “cuts” into the rolls. Up to 0.100- to 0.150-in. (2.5- to 3.8-mm) deep grooves can be worn into the hardened rolls by the scale which flaked off from the hot rolled steel.
- Shims (if any) identified by their thickness should be installed at the location marked on the setup chart.

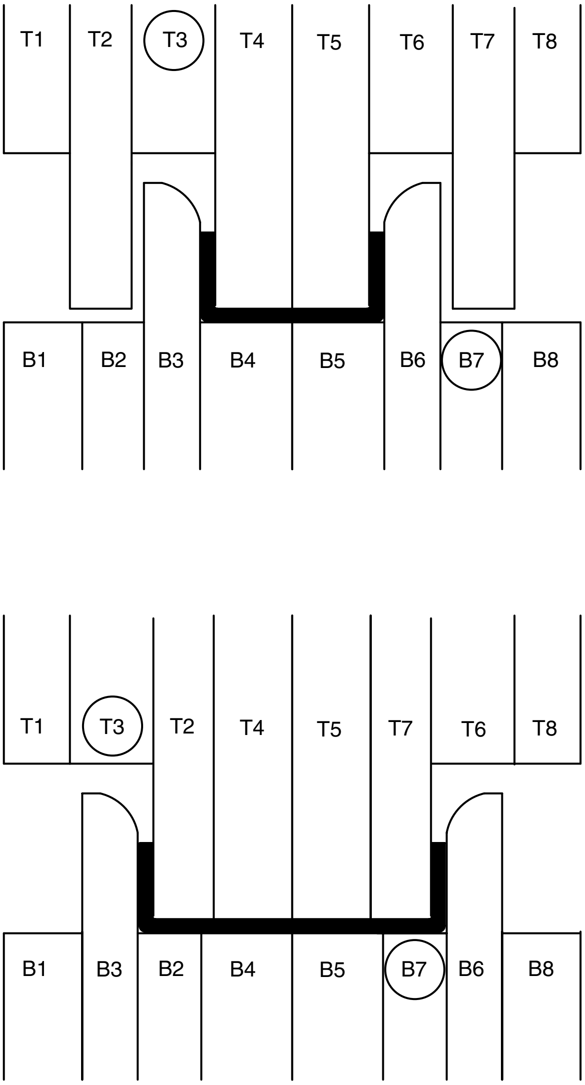


FIGURE 10.13 Multipurpose rolls can be placed in different locations (not following numerical sequence) as shown in the lower drawing.

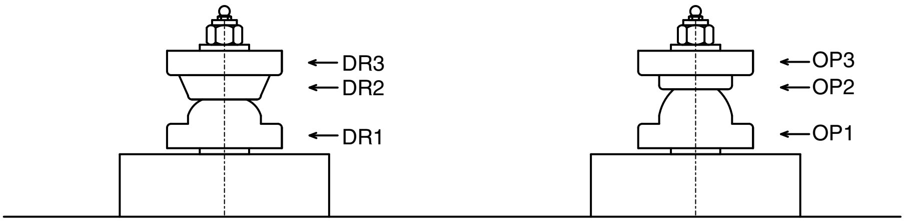


FIGURE 10.14 Setup of segmented side-rolls follows the number sequence (OP [operator side], DR [drive side] and #1 — install first).

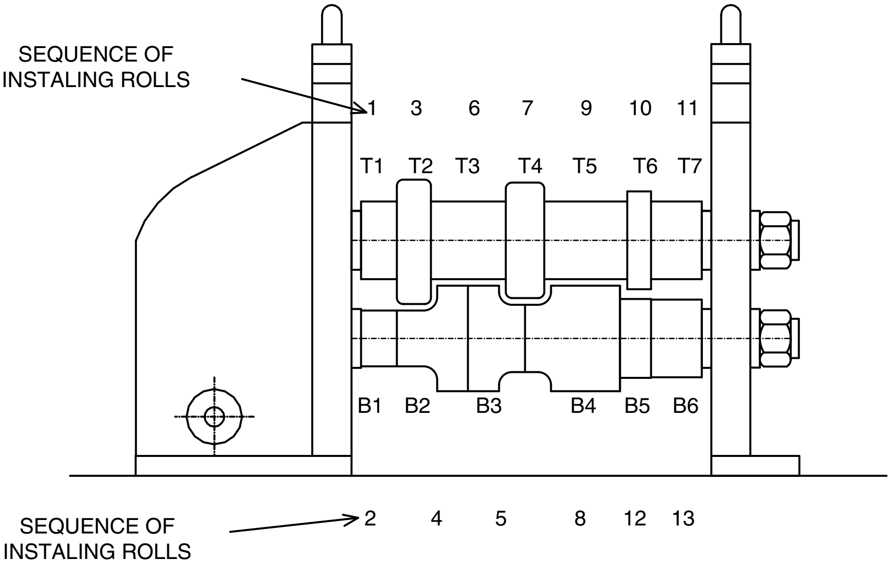


FIGURE 10.15 Roll diameters dictate the sequence of roll installation.

- Installation of rolls usually starts at the last pass (closest to the press) by placing the first top and bottom spacers or rolls on the shafts (check carefully the "T" or "B" marks on the rolls or spacers).
- When all the top and bottom rolls, spacers. and shims are on the shafts, push the outboard stand back into position. (Watch your fingers!)
- Place both the top and bottom nuts on the shaft ends and tighten the bottom nut first, then the top nut.
- Slide the outboard stand in and out until it is roughly in the middle of the long bearing sleeves located in the bearing blocks of the stand.
- Bolt the outboard stand to the mill base.

10.2.3 Checking Roll Gaps

- Select a setup gage to suit the material thickness (maximum specified material thickness, including "plus" thickness tolerance, coating, embossing, etc.).
- Check the horizontal gaps with feeler gages on both the drive side and operator side of the profile (Figure 10.17). Setting screws should always be turned downwards for the final adjustment of the top shaft.

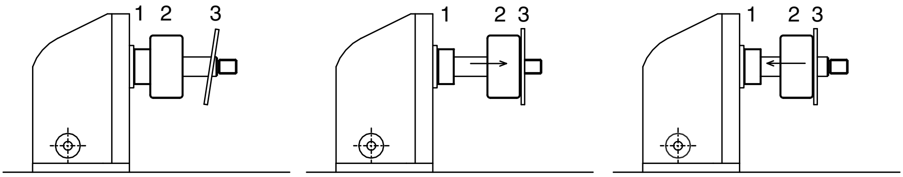


FIGURE 10.16 Short, thin roll (#3) wedges easily on the shaft; it can be installed with the help of an already installed, longer roll or spacer.

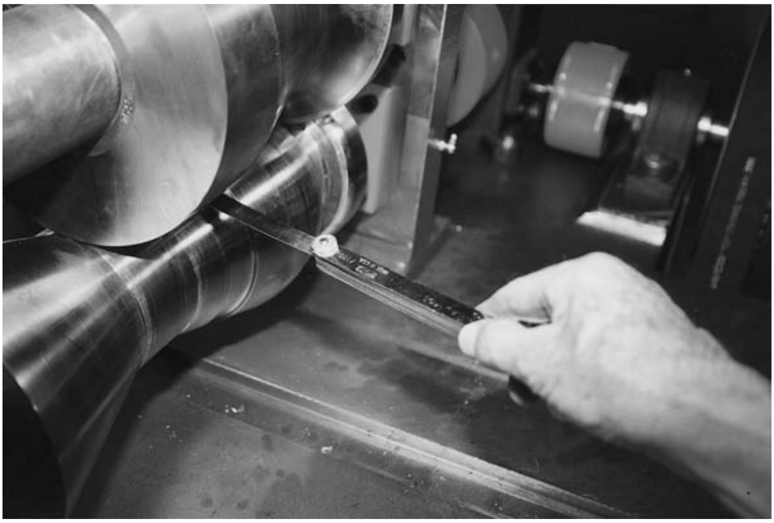


FIGURE 10.17 Checking gap with a feeler gage.

- Check the nonhorizontal gaps (adjust as above, check shoulder alignment or shim if required).
- However, checking the gaps with feeler gage alone may not be sufficient (Figure 10.18) even if all the rolls appear to be in the correct position.
- Double check the gaps between rolls with a mirror (Figure 10.19).
- Check the thickness, width and other specifications of the material to be formed.
- Enter (jog) the material through the mill, pass-by-pass.

Adjust set screws down if the roll gap is too big, and up if the pressure is too much (make the last adjustment always down)

- Check the dimensions of the finished product.
- Check deviation from straightness and flatness.
- Check the product surface.
- Check again after rolling with lubrication applied (if lube was not used during setup).
- Check other items on the mill (e.g., entry guide). For setting straighteners, see Section 10.2.4.
- Check other items on the line including: length measuring devices or counter setting, safety devices, uncoilers, presses, and so on.
- Run a few pieces at normal speed and check parts before starting production.

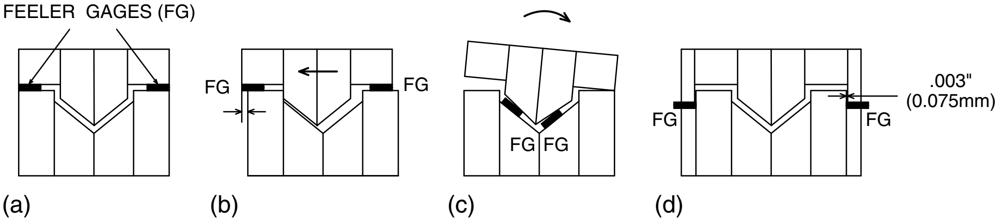


FIGURE 10.18 After checking the gaps with feeler gages (a–c), the roll gap can still be incorrect, but it is better to have “locked” rolls (d).

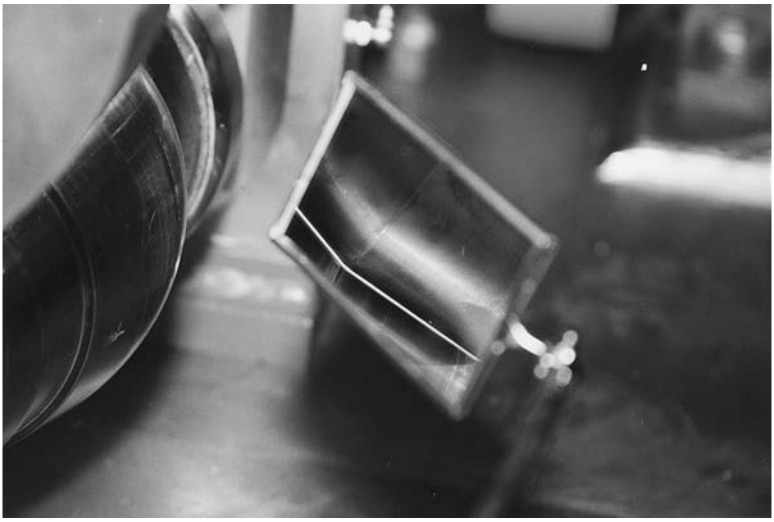


FIGURE 10.19 Checking roll gaps with mirror.

10.2.4 Setting up Straighteners

Given the wide variety of straighteners used in roll forming, there is no standard procedure for setting up straighteners, but the following principles are applicable:

- Remove straightener (block, rolls, or complete unit).
- During roll setup, try to produce parts as straight as possible without the straightener.
- After roll setup is completed, install the straightener as close to the last pass as possible.
- Adjust the straightener to produce straight and flat products.
- The straightener should be used for straightening only, and not for improving incorrect forming.

10.3 Maintenance and Spare Parts

10.3.1 Manuals

A properly maintained, reasonable quality, roll forming line will have an average of 50 years of productive life. Every new piece of equipment is accompanied by at least two copies of good "installation, setup, operation, and maintenance" instruction manuals. These manuals provide the basic information on equipment layout, foundation details, roll setup drawings, electrical, pneumatic, and hydraulic diagrams, and contain copies of the manuals for the purchased parts (pumps, motors, clutches, brakes, etc.).

Most manuals list the components that may require replacement and include recommendations for maintenance. It is the responsibility of the roll former line end-user to establish a detailed maintenance procedure.

10.3.2 General, Preventive, Predictive Maintenance Program

The manual supplied with the equipment provides a general outline of the installation, operating, and maintenance procedures. The manual can be 1- to 6-in. (25- to 150-mm) thick, which is too cumbersome for everyday use. Selected contents of the manual should be organized into simplified, preventive, predictive, or other type of maintenance procedures, which are tailored to the company's equipment, people and organization.

Providing verbal maintenance instructions can be dangerous because the maintenance person may forget to complete each task every time. It is also uncertain how well the procedure will be followed when the trained maintenance person is on vacation or has left the company.

Some companies issue “maintenance work orders” or “maintenance cards,” while others have more sophisticated, computerized programs. The maintenance program must be prepared by a person who is knowledgeable about the roll forming mills, presses, other equipment in the line, electrics and electronics, pneumatics, hydraulics, lubrication, and other fields. The execution of the maintenance program has to be controlled, breakdowns and accidents reported and the maintenance procedure should be updated regularly.

10.3.3 Lubrication Program

This section deals with all lubricants except the ones used on the rolls and material during forming. Those lubricants are described in Chapter 7 (“Lubrication”).

Most companies own several pieces of equipment made by different manufacturers, each of whom recommend the use of different lubricants. It is logical and economical to review all the recommended lubricants, check for equal quality substitutes, and specify common types of lubricants that are applicable to as much equipment as possible. This will reduce costly inventory and even more costly “inventory outs” when required lubricants are not available. It also eliminates dangerous “guess” substitutions by the employees.

A typical chart for standard lubricants established for a company is shown in Table 10.1. This type of chart must also be updated regularly. The recommended “in-house standard lubricants” should be transferred to the individual lubrication maintenance instructions.

The lubrication procedure should also specify how to store and dispose of lubricants.

10.3.4 Lubrication Instruction

The lubrication instructions specify the type of lubricant and the frequency of application for each lubricant point. A pictorial view of each piece of equipment can be very useful; it will minimize confusion and reduce the possible damage due to missed or incorrectly lubricated points. Table 10.2 and Figure 10.20 show a typical lubrication for a specific roll forming mill. A similar instruction for a variable speed reducer is shown in Table 10.3 and Figure 10.21, and for a cutoff press in Figure 10.22.

10.3.5 Mill Maintenance

Mill maintenance is similar to all other equipment maintenance. Mill maintenance procedures include but are not restricted to:

- Checking and replacing components
- Checking and, if required, realigning parts, entry guides, straighteners, equipment on the mill, and the lubrication system (covered in Chapter 7)
- Checking the tightness of bolts and nuts, including the foundation bolts
- Lubrication (mentioned in Section 10.3.3)
- Occasional repainting of the equipment, and more

The components to be regularly checked in the roll forming mills are listed below.

10.3.5.1 Shafts

The rigidity of the shafts is checked every time the tool is changed. The straightness of the shaft can be checked with a mirror during each setup. Both the rigidity and the straightness of the shaft should be

TABLE 10.1 Standard Lubricants, Greases, and Cleaners (Sample Chart)

Mfgr.	Type	Supplier	Description	Use	Company code	ISO grade
A	b	c	Spindle oil	Air line oilers — light lubricant	0-1	7
D	e	f	Hydraulic oil	Hydraulic systems oil	0-2	68
A	g	f	Stamping oil	Stamping dies — Dept. 001	0-3	
H	i	j	Cutting oil	Cutoff on cold headers	0-4	
and so on	and so on	and so on	General lube	Gear oil for small drives Manzel lubricators Dept. 001	0-5	150
			Way oil	Bijur lubricator on multislide Dept. 001 lubricate sliding ways	0-6	220
			Hydraulic oil	Hydraulic systems oil	0-7	32
			Extreme pressure gear oil	Worm gears and heavy-duty gear drives	0-8	320
			Stamping oil	Stamping die	0-9	
			Hydraulic oil and general lube	Piston compressor	0-10	100
			Extreme pressure oil	Lube chain on plating line	0-11	68
			Auto transmission fluid — hydraulic fluid	Screw compressor, tracking units, new roll coater	0-12	
			Hydraulic oil	Hydraulic systems oil	0-15	46
			Rust preventive	Coat dies and molds	0-17	
			Grease	Auto lubricator on verti-slide	G-0	
			Grease	Auto greaser — Dept. 008	G-1	
			Grease	General plant grease	G-2	
			Tapper grease	Aro tapper, verti-slide	G-3	
			General purpose grease	Mill heads	G-6	
			Safety solvent	Magnus washers	CC-1	

checked at least once every 6 months, when mishaps happen or when a problem with product quality warrants it.

If shafts are loose, then the bearings have to be tightened or replaced. If shafts are bent, then they can either be straightened or chrome-plated, reground, or replaced. In all cases, the shaft shoulders have to be realigned by using a 6 ft (2 m) precision straight edge or other methods described in Section 10.3.9. If the mill has shoulder alignment spacers, then the spacers must be replaced or reground every time a shoulder is realigned.

Small scores on the shaft can be removed with a fine file or emery paper. Heavily scored or worn shafts may have to be repaired or replaced.

TABLE 10.2 Typical Lubrication Instructions for the Roll Forming Line Shown in Figure 10.9 (Sample Chart)

RF Mill Components	Lubrication Points
Roll unit:	
Drive housing	*Grease* (4) places at 500 hr; *Note*: (2) places on old S.F. unit Gear *lube* — keep to full time
Outboard stand	*Grease* (2) places at 500 hr
Entry guide	*Grease* (5) places: (4) rollers at 40 hr shaft bearing at 500 hr
Knurling unit	*Grease* (4) roll bearings at 8 hr *Oil* all slides and adjusting screws at 40 hr
Drive shaft bearing	*Grease* (2) places at 500 hr
Straightener	*Grease* roll bearings at 40 hr, adjust screws at 500 hr *Oil* all slides
Air lubricator	*Oil* keep full
Drive	See "Drive Chart" (electric motor serviced by maintenance)

Company lube code: air lubricator oil, 0-1; gear lube, 0-8; general oiling, 0-2.

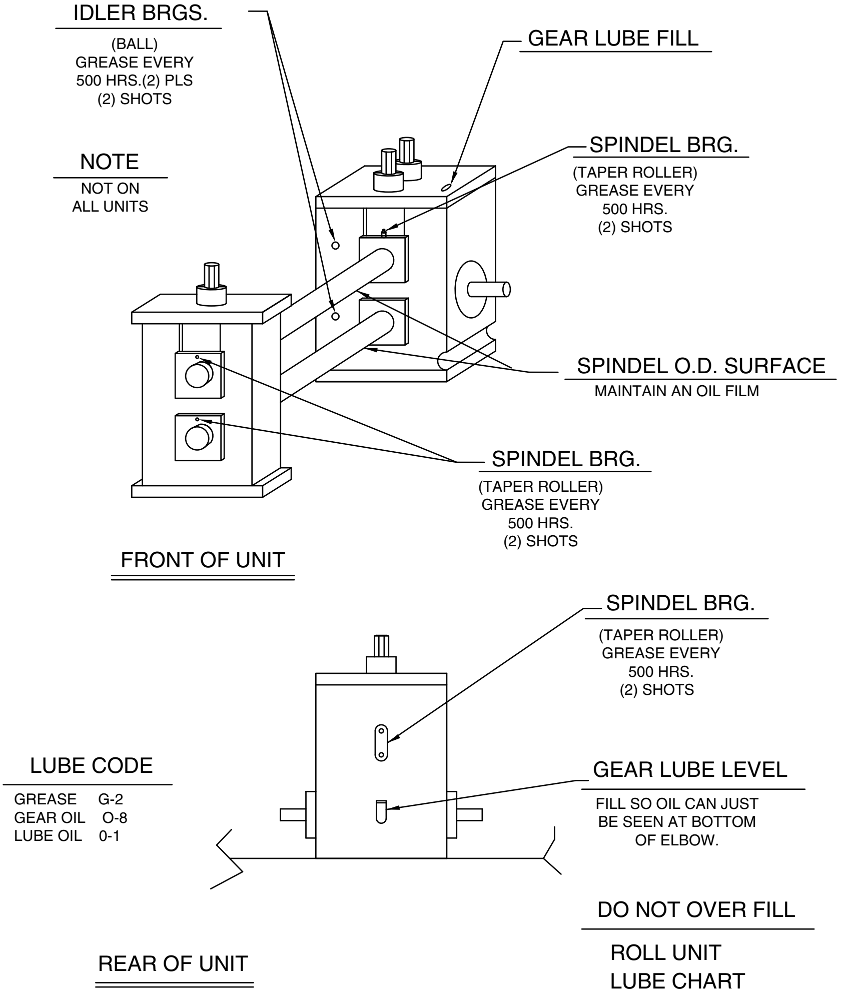


FIGURE 10.20 Typical lubrication instructions for roll forming stand (see also Table 10.2). (Courtesy of Kirsch Co.)

TABLE 10.3 Typical Lubrication Instruction for the Roll Forming Line Shown on Figure 10.9

Interval	Lubrication
Every 40 running hours	Cycle through entire speed range No lube
Every 160 running hours	Grease points "B" (2) places (sliding disk bearing surfaces) 2 shots each: 1 shot "high" end of cycle, 1 shot "low" end of cycle
Every 960 running hours	Grease points "A" #500 — (2) places/#6000 (4) places. (shaft end bearings or thrust bearings (3) shots each)
Every 1500 running hours	Grease points "C" (2) places (Motor) to be serviced by maintenance department. These points are omitted on units with sealed bearings

Company lube code: Grease G-2, *Do not over grease.*

10.3.5.2 Gears

Gear failure, caused by wear and pitting, is accelerated by overload, dirt, and grit and the lack of or insufficiently maintained lubrication. Dirt and grit gets into the gear because of damaged or nonexisting seals. Gear cracking and breaking off teeth is usually caused by regular overload or sudden, very high loads. The teeth of heavily worn gears can also break off at normal load.

If rolls have been recut, then the operator must lower the top shaft to maintain the proper roll gap. If the roll has been recut too much (the diameter becomes too small), it is possible that the shaft distance will be less than the recommended minimum, based on the pitch diameter. In this case, spur gears can "bite" into each other. Operating the gears at a pitch distance less than the minimum will generate noise and vibration, which creates clearly visible "chatter" marks on the surface of the product (Figure 10.23).

If gears are running in an oil bath, then the oil level should be checked frequently, right after the mill stops. Oil leaks should be repaired not only to avoid oil loss from the gearboxes, but also to eliminate contamination of the lubricants used for forming the section.

Improper gear alignment, sometimes caused by bearing failure, can also contribute to gear failure.

All gearboxes should be opened at least once every 3 months for a visual check. If the temperature of the stand or the gear reducer rises, vibrates, or runs noisily, then it should be checked as soon as possible.

10.3.5.3 Bearings

Roll forming mills contain many bearings. The life of the bearings is designed for a certain number of hours at a given load. As a bearing wears, the surface of the inner and outer rings and the rolling elements changes. This change creates vibration and sound. Most bearings in the roll forming line have a long life. They are infrequently inspected unless vibration, noise or undue heat is generated.

The bearings carrying the shafts in the stands are critical and should be frequently checked. The operator side of the shafts usually runs in needle bearings. Wear on the usually overdesigned needle bearings is minimal. If these needle bearings are damaged, then the problem is usually caused by lack of lubrication, sudden overload (double- or triple-thickness material passing through the rolls), or by a very high bending moment created by the operator when lifting one end of the shaft too much (Figure 10.24). Cracked or broken bearing components frequently generate vibration or a "clicking" noise. These low-cost bearings can be replaced quickly and easily.

The drive-side end of the shaft is held by cone bearings. A small wear on the bearings will make the shaft loose. When the outboard stand and the rolls are removed and the free end of the shaft can be moved up or down easily, it is time to tighten the bearings. After a few adjustments, it cannot be tightened anymore and the bearing has to be replaced.

Roll forming mill bearings occasionally fail because an incorrectly selected forming lubricant has leaked into the bearing houses and dissolved the bearing lubricant. Abrasive particles, such as scale from hot-rolled steel, can drastically reduce bearing life. Maintaining good seals on the bearings is critical.

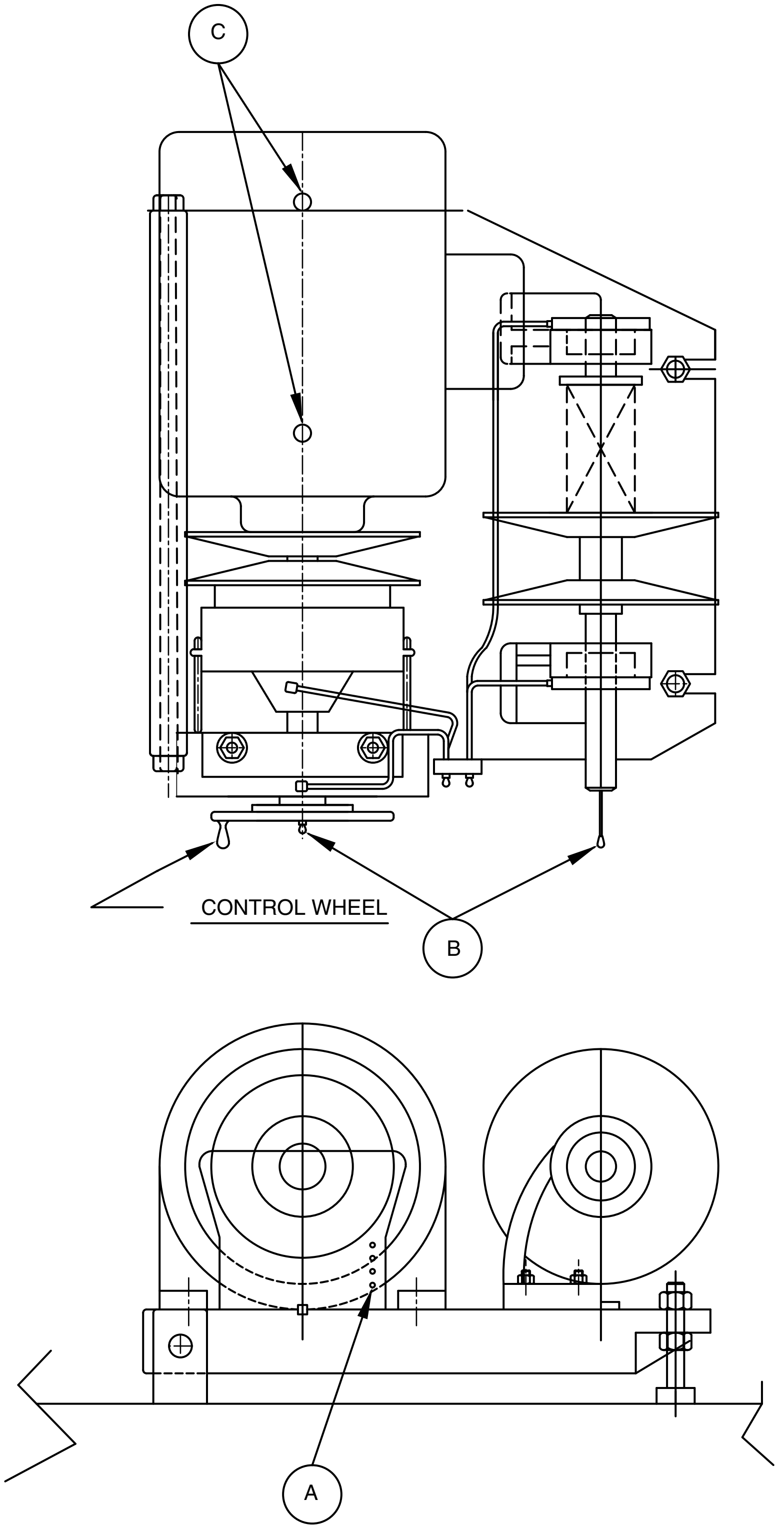


FIGURE 10.21 Typical lubrication instructions for a variable speed drive (see also Table 10.3). (Courtesy of Kirsch Co.)

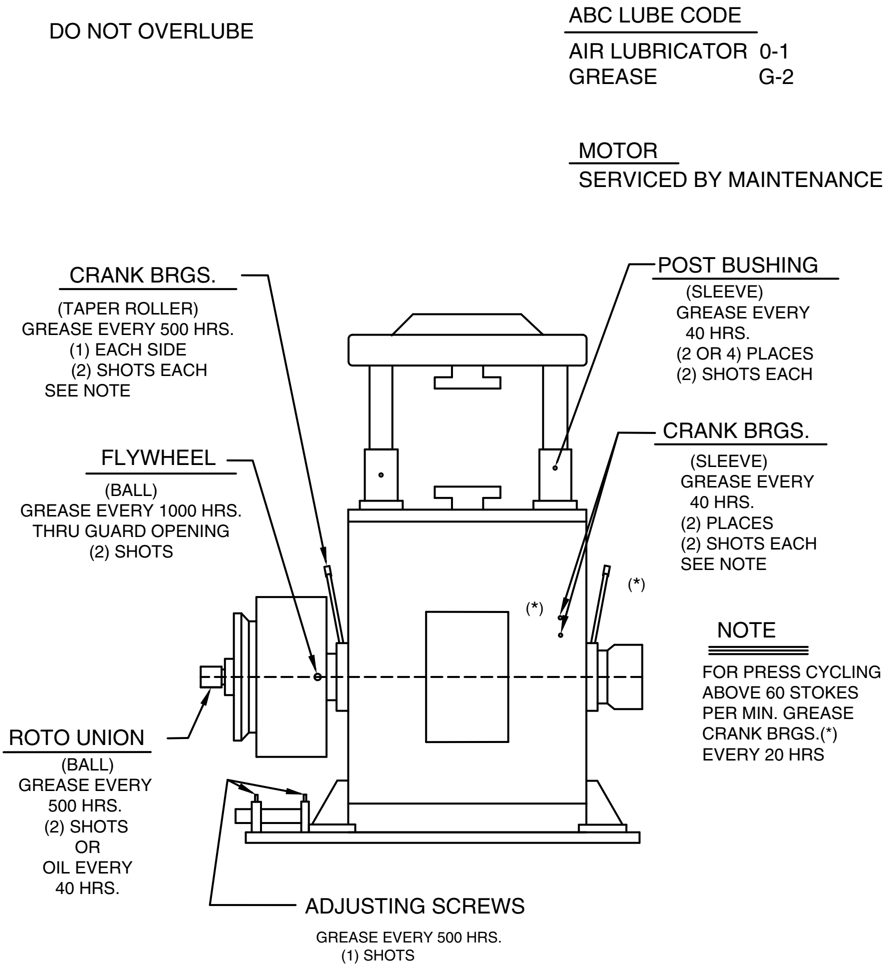


FIGURE 10.22 Typical lubrication instructions for a mechanical press. (Courtesy of Kirsch Co.)

The other bearings on the mill, most of them located in the drive train, work under less critical conditions, but occasional inspection is still important. All bearings in the drive train must be properly aligned. Misalignment caused by improper installation or by too high belt tension will reduce the life of the bearing, gears, and other components.

Bearings are removed and installed with proper tooling to evenly distribute the load and to prevent dirt from entering into the bearings during mounting.

Incorrectly installed, inadequately lubricated or worn-out bearings also generate noise and heat. Operators can easily detect failing bearings by listening to the noise or by feeling the vibration or the increased temperature by hand. More sophisticated temperature monitors and listening stethoscopes can provide a good indication of existing

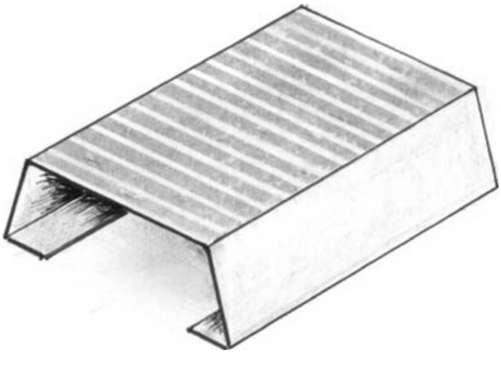


FIGURE 10.23 Gear chatter marks on the product.

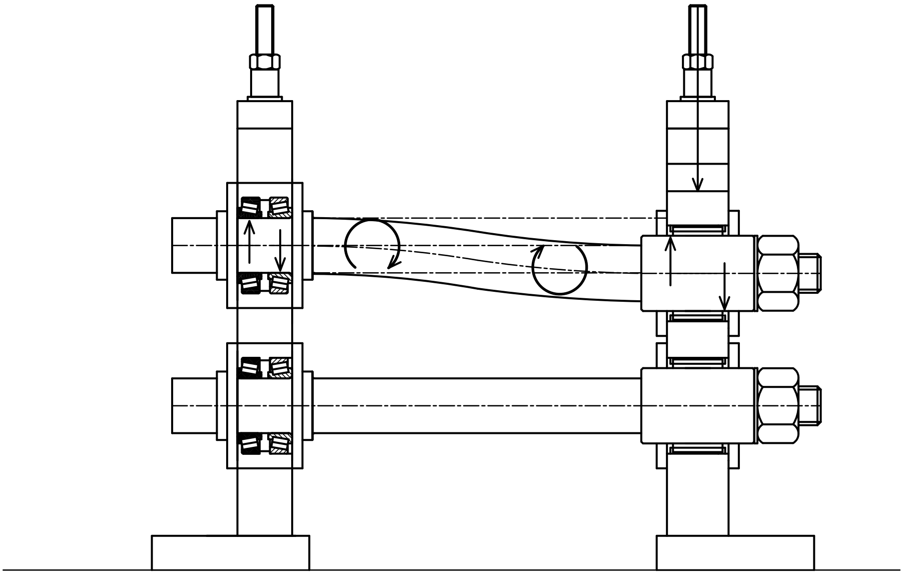


FIGURE 10.24 Forcing one end of the shaft up or down exerts undue high pressure on the bearings.

bearing problems. Vibration analysis is more accurate in predicting problems, but is very seldom used on roll forming mills.

The drive motor, clutch, and other bearings should be checked and maintained according to the supplier's recommendations.

10.3.5.4 Drive Belt and Chain

Drive belts and sometimes chains are used to transmit power from the motor to the drive train of the mill. Occasionally, variable speed selectors with belts are used for this purpose.

Belts usually require minimal maintenance when they are properly installed. During installation, avoid prying the V-belt into the grooves. Place the belts on the sheave and then apply tension.

It is important that the shafts be parallel and the sheaves accurately aligned. Alignment can be checked with a straight edge. V-belts will fail quickly when entering and leaving misaligned grooves.

Proper tensioning is an important factor. The supplier's recommendation for the lowest level of belt tensioning should be followed. Proper tension should be checked frequently during the first few days of operation and the necessary adjustment(s) should be made. When one V-belt of any multiple belt drive requires replacement, always replace all the belts with new ones made by the same manufacturer.

Always keep the belts properly guarded for safety and to prevent oil from dripping and dirt from entering into the belts.

10.3.5.5 Mill Stands

Most mill stands are sturdily built and they can last without replacement for more than half a century. However, in addition to the previously described bearing and gear maintenance, some components of the stands have to be regularly checked and maintained.

The adjusting screws slide up and down the bearing blocks in both the operator-side and the drive-side stands. The sliding part of the bearing block can wear out. If the wear at the front or rear sides becomes noticeable, then depending on the construction of the stand, the bearing block has to be made tighter either by changing the shims or by remachining the parts.

The lower ends of the rotating adjusting screws are encased at the top of the bearing block (Figure 10.25). These seldom-lubricated rotating parts can wear out. Once they are worn, the bearing blocks,

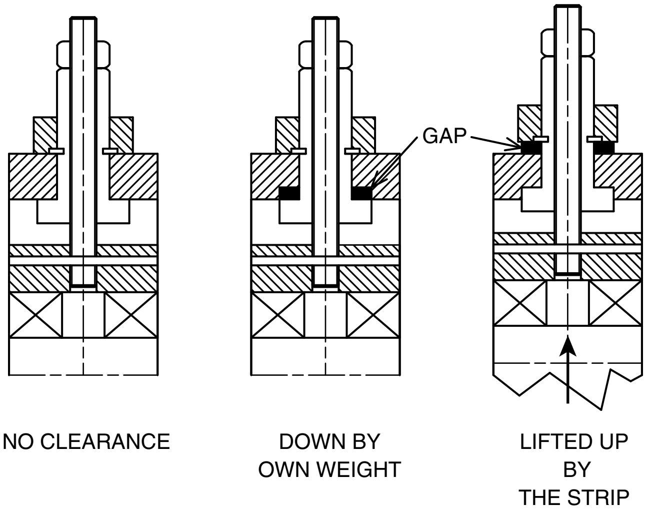


FIGURE 10.25 Worn, old-style top bearing block lifting screw allows the shaft and rolls to drop under their own weight. The rolls will then be lifted up by the product entering between them.

shafts and rolls "hang" on the screw by their own weight. As a result, after the roll gap is set to the right distance with feeler gages, the top shaft with the rolls will jump up when the material enters between the rolls. To avoid this "jump," and to ensure correct setting of the roll gap, this looseness (play) has to be eliminated. "Tightness" can be achieved either by reworking the end of the lifting screws and the encasing parts, or by placing a urethane block under each bearing block (Figure 10.26) The elastic urethane lifts the block up sufficiently to eliminate the "play" and permits the gap to be set properly with feeler gages. The elastic urethane, cut to the right length, does not impede roll adjustment downward. A few manufacturers supply mill stands with springs lifting the top blocks.

From time to time, the alignment of the micrometer scales on the operator- and drive-side screws should be checked. After setting the shafts parallel with feeler gages between the rolls, the scales at both stands have to be set to zero (Figure 10.27). This will help the operator keep the top shaft parallel to the bottom one regardless of the gap size.

All adjusting screws should run freely. Worn and damaged screws require more force to turn them, which will prevent the operator from "feeling" the pressure on the rolls during setup.

Suppliers usually do not number the roll forming stands. However, they are counted hundreds and thousands of times during the life of the mill. Operators occasionally mark them with felt pens. It is advisable to have permanent identifications numbers installed on the stands, starting with #1 at the entry side of the mill (Figure 10.28).

All mills run left to right or right to left. The right- and left-handed nuts at the shaft ends are always tightened in the opposite direction of the shaft rotation. Therefore, mills cannot be operated running in the opposite direction. The nuts will always get loose if the mill is running in the wrong direction.

The supplier usually marks the left-handed nuts with a groove (Figure 10.29). If they have not been marked, the marking should be made retroactively. Grooves on the nuts will save a considerable amount of the operator's time by eliminating the irksome attempts to install left-hand threaded nuts on right-hand threaded shafts and *vice versa*.

Nuts should run "freely" on the shaft-end threads when rotated by fingers. Use reasonable torque when tightening the nuts, but avoid overtightening them. For nut tightening, do not use long extensions on wrenches, sledgehammers, or high torque pneumatic nut runners. However on nondriven shafts, a hit with a hammer on the wrench will help to open (or close) nuts.

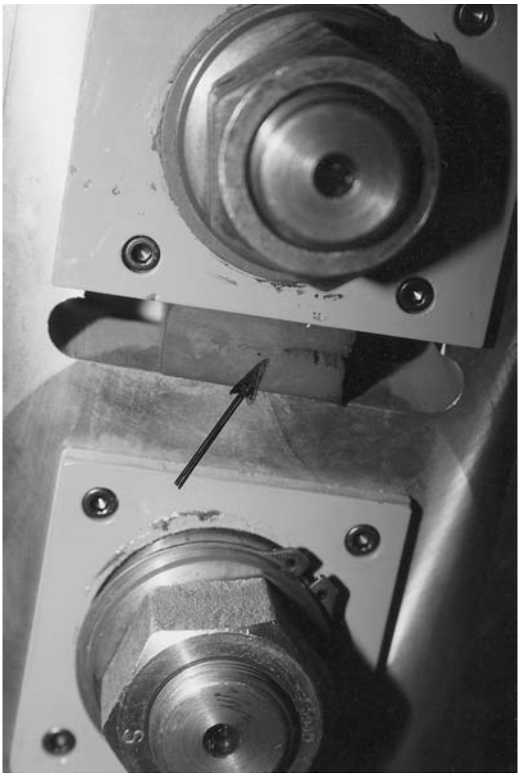


FIGURE 10.26 Urethane block lifts the loose bearing block up and eliminates the upper shaft "jump" when the material enters the rolls.

If the stands and the mill bed are repainted, use compatible machine paint that will not be dissolved by the lubricants.

10.3.5.6 Other Mill Components

Other components of the roll forming mills such as entry rolls, entry guides, side-roll stands, straighteners, and others should be maintained and lubricated according to the supplier's recommendation.

10.3.6 Maintenance of Mechanical Presses

All presses require regular (preventive and predictive) maintenance. The instruction/maintenance manuals supplied by the press manufacturers cover the press maintenance procedures. Recommended press lubrication is covered in Section 10.3.

Listed below are the guidelines for items to be checked or replaced during regular maintenance of prepunching and cut-to-length presses:

- Check all bolts and nuts and tighten loose ones.
- Check the nuts on the press posts, holding the press head.
- Check parallelness of the head with the base after the nuts are tightened.
- Check that the press stops at TDC (top dead center).
- Adjust the clutch if required and check the lining for wear.
- Adjust the brake if required and check the lining for wear.
- Check the position of the microswitches at the cam located at the end of the crankshaft, other sensors, or timing devices involved in the press-cycling and flying-die motion.

- Check the condition of the roto-union.
- Check all air hoses and accessories for leaks, cracks, free movement, and so on.
- For flying dies, check the locations of the cutting or punching (should be at the center of the press), the sensors and the die rails (fasteners, wear, etc.)
- Check for a proper fit between the die rails, slides, and die accelerator components
- Check the condition of the belts
- Release water from the air tank, and other accumulating points
- Check the condition of the press posts (score marks)

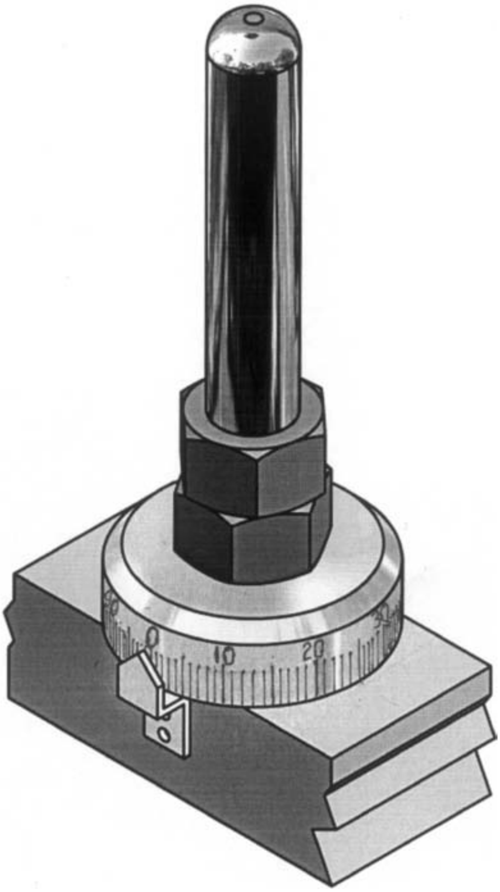


FIGURE 10.27 Micrometer scale is set to "0" at both the drive- and operator-side stands after the shafts are set parallel.

10.3.7 Maintenance of Hydraulic and Pneumatic Presses

Several items listed above (Section 10.3.6) are applicable to the hydraulic and pneumatic press too. The supplier's manuals provide good guidelines for regular maintenance. In addition to those, it is important to eliminate all, even the smallest air and oil leaks, check the condition of hoses, check all bolts and nuts (and tighten loose ones), and check the parallelness of the head. Items related to flying dies are discussed in the "Maintenance of Mechanical Presses."

10.3.8 Maintenance of Other Equipment in the Line

In addition to checking the wear and tear and lubrication of the entry guides, side-roll stands and straighteners, the maintenance of other items can be based on the information and maintenance guidelines provided by the suppliers.

10.3.9 Aligning Mill Shaft Shoulders

The following is a widely used and recommended method to align shaft shoulders in standard roll forming mills (shafts supported at both ends). Some components of this aligning method are applicable to rafted and duplex mills.

- Remove rolls
- Check the end of the shafts for stiffness by moving them up and down
- Tighten/change bearings (if required)
- Install outboard stands (without bolts)
- Set top/bottom shafts parallel
- Check shaft straightness (0.001 to 0.003 in. or 0.025 to 0.076 mm; with outboard stand on). See Figure 10.30.
- Install the "V" groove spacers on the first and the last pass bottom shafts

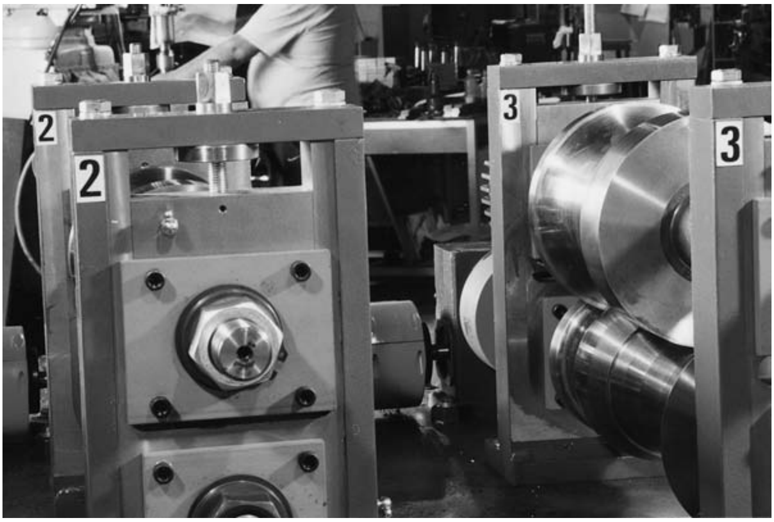


FIGURE 10.28 Permanent numbers installed on stands. (Courtesy of CompuRoll, Inc. With permission.)

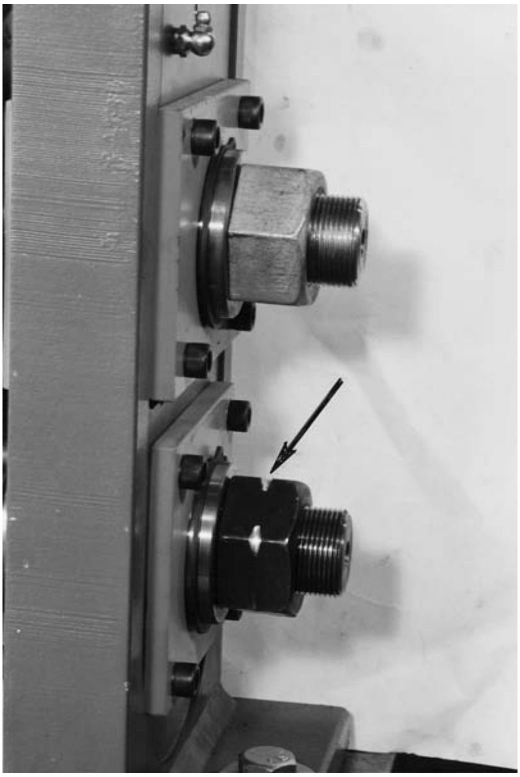


FIGURE 10.29 Left-hand threaded nuts are permanently marked. (Courtesy of CompuRoll, Inc. With permission.)

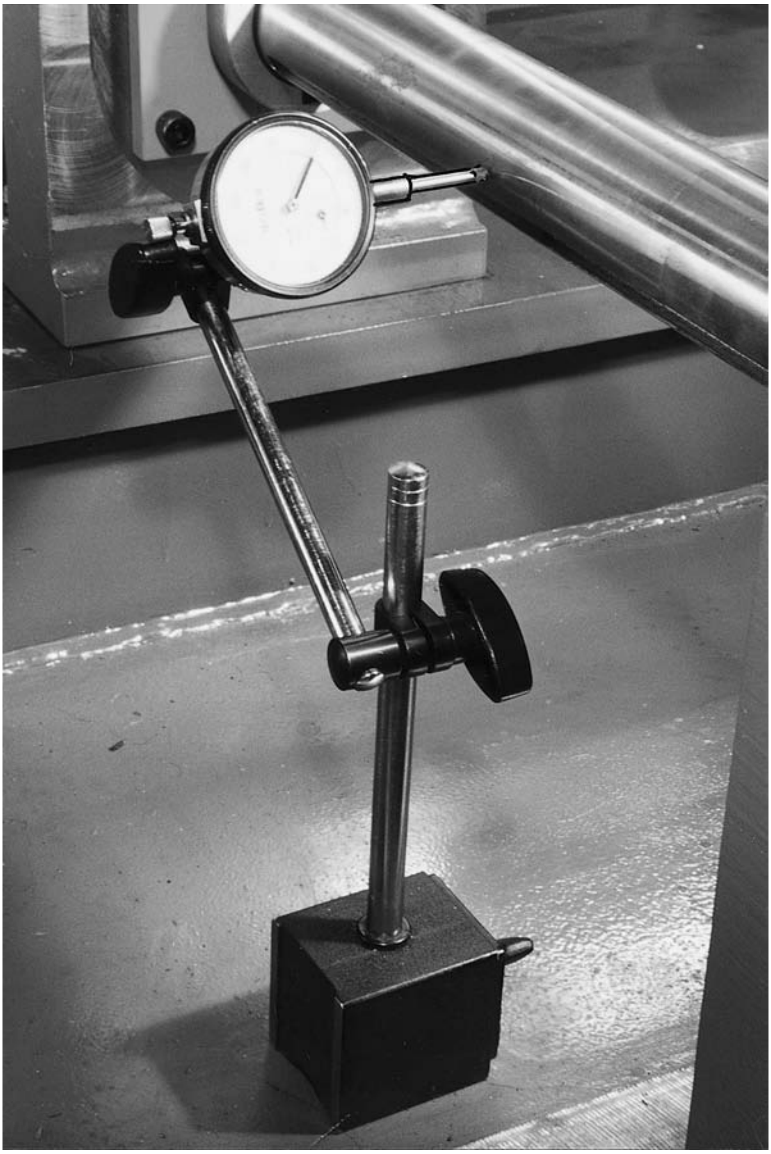


FIGURE 10.30 Checking the straightness of a shaft.

- Install music wire into the “V” grooves
- Check and note all bottom shoulder positions relative to the strung wire (Figure 10.31) to 0.001 in. (0.25 mm). A typical chart used during shoulder alignment is shown in Table 10.4.
- Make shoulder alignment spacers within 0.0005 in tolerance to compensate for the shoulder alignment differences
- Mark spacers B1, B2, B3, and so on, to match the first, second, third stands
- Install all bottom alignment spacers
- Check alignment with a 6-ft (2-m) long precision straight edge (Figure 10.32 and Figure 10.33). Spacers should be aligned within 0.001 to 0.003 in. (0.025 to 0.075 mm), depending on the specification and type of products

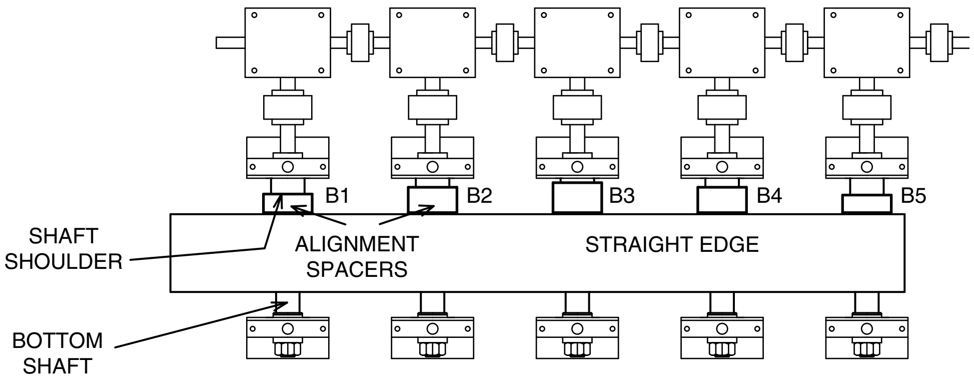


FIGURE 10.31 Aligning shaft shoulders.

- After setting the top shafts parallel to the bottom shafts, measure and note the top shoulder positions measured from the bottom alignment spacer (Figure 10.34)
- Make top shoulder alignment spacers as described above for bottom spacers
- Mark top alignment spacers as T1, T2, T3, and so on.
- Install all top spacers and check their alignment with the straight edge as described above
- Spot check the alignment of the top and bottom spacers (different methods are available). The spacers should be aligned within 0.0005 to 0.002 in. (0.012 to 0.050 mm), depending on the product and material thickness.
- Check shaft straightness again with rolls on. Roll surface "off roundness" should be within 0.0005 to 0.002 in. (0.010 to 0.050 mm), depending on the product.
- Never remove the shoulder alignment spacers when changing tooling. However, shoulder alignment should be rechecked and either reground or replaced every time the bearings are tightened or replaced, after each accident or maintenance work which can affect shoulder alignment.

Relatively inexpensive shoulder alignment instruments are available, which can considerably reduce the time required to align the shoulders and at the same time increase the alignment accuracy (Figure 10.35).

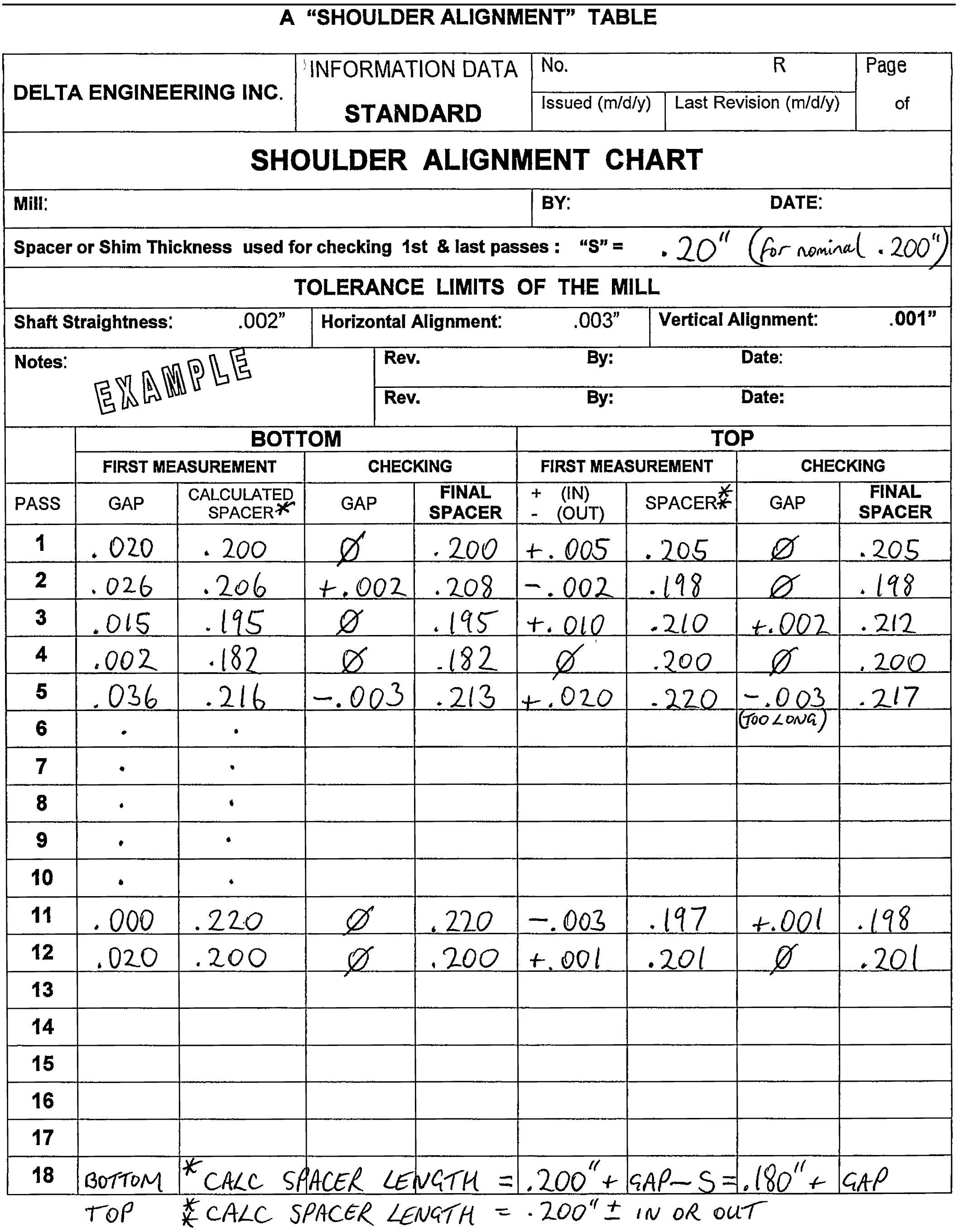
10.3.10 Handling and Storing of Rolls and Tools

Rolls and spacers are precision forming tools. They have to be carefully handled and stored when not in use. It is not recommended to store them in boxes, piled on top of each other. They can be easily damaged and chipped, and it is then difficult to place them back on the mill in the correct order.

Most roll storage devices are homemade. Some are like metal skids with vertical tubes welded on them. Operators can place the rolls in the same sequence that they were taken off the shaft. Storing the rolls on these metal skids is better than just putting them in a box, but it is difficult to put on and remove heavier rolls from these tubes. Horizontal or slightly slanted tubes with a stop at the ends are the most common, because it is relatively easy for the operator to place and remove the rolls using these devices (Figure 10.36). Most of these storage units can be stacked on top of each other to save space, and they can be placed on a mobile table or other device, which can be pushed along the length of the roll forming mill.

Heavier rolls may be pushed on to "dummy shafts" held against the end of the mill shafts by a lifting device or forklift truck (Figure 10.37). The rolls and spacers are slid from the shaft to the dummy shafts or vice versa without lifting. When the dummy shaft is full, it is moved with a lifting device and placed in storage.

TABLE 10.4 A Shoulder Alignment Table



A "SHOULDER ALIGNMENT" TABLE

DELTA ENGINEERING INC.	INFORMATION DATA **STANDARD**	No. R Issued (m/d/y) Last Revision (m/d/y)	Page of

SHOULDER ALIGNMENT CHART

Mill: **BY:** **DATE:**

Spacer or Shim Thickness used for checking 1st & last passes : "S" = .20" (for nominal .200")

TOLERANCE LIMITS OF THE MILL

Shaft Straightness: .002"	**Horizontal Alignment:** .003"	**Vertical Alignment:** .001"

Notes: EXAMPLE

Rev. **By:** **Date:**

Rev. **By:** **Date:**

	BOTTOM				**TOP**			
	FIRST MEASUREMENT		**CHECKING**		**FIRST MEASUREMENT**		**CHECKING**	
PASS	GAP	CALCULATED SPACER*	GAP	**FINAL SPACER**	+ (IN) - (OUT)	SPACER*	GAP	**FINAL SPACER**
1	.020	.200	0	.200	+.005	.205	0	.205
2	.026	.206	+.002	.208	-.002	.198	0	.198
3	.015	.195	0	.195	+.010	.210	+.002	.212
4	.002	.182	0	.182	0	.200	0	.200
5	.036	.216	-.003	.213	+.020	.220	-.003 (TOO LONG)	.217
6	.	.						
7	.	.						
8	.	.						
9	.	.						
10	.	.						
11	.000	.220	0	.220	-.003	.197	+.001	.198
12	.020	.200	0	.200	+.001	.201	0	.201
13								
14								
15								
16								
17								
18	BOTTOM	*CALC SPACER LENGTH =			.200" +	GAP—S =	.180" +	GAP

TOP *CALC SPACER LENGTH = .200" ± IN OR OUT

Rolls mounted on rafts are moved together with the rafts and stored.

Keep all rolls in a dry place regardless of the handling and storage method. Coat rolls with oil or grease if they are not used for a long period of time.

It is recommended that cutoff dies be sent to the tool or maintenance room for inspection together with the last (short) cut from the last production run. After checking or sharpening,

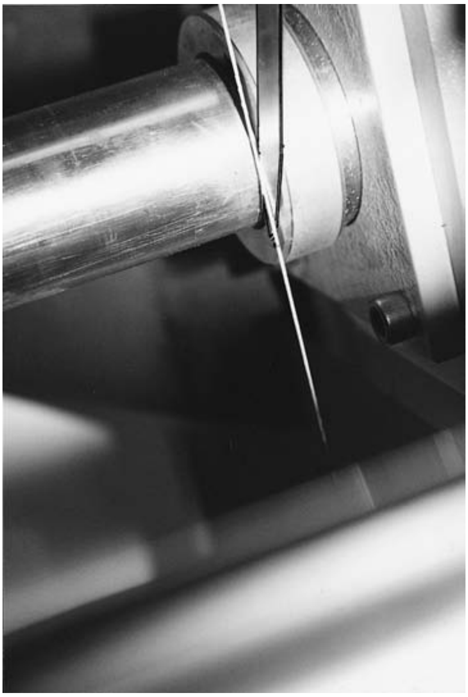


FIGURE 10.32 Checking the misalignment of each bottom shaft shoulder with stretched wire.

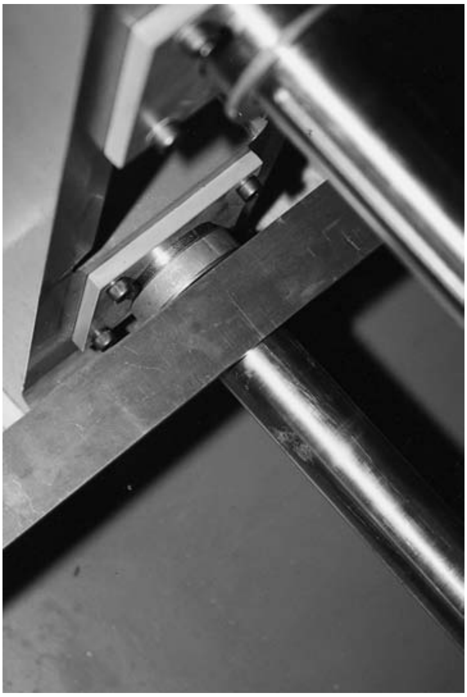


FIGURE 10.33 After installing the alignment spacers, the operator side will line up.

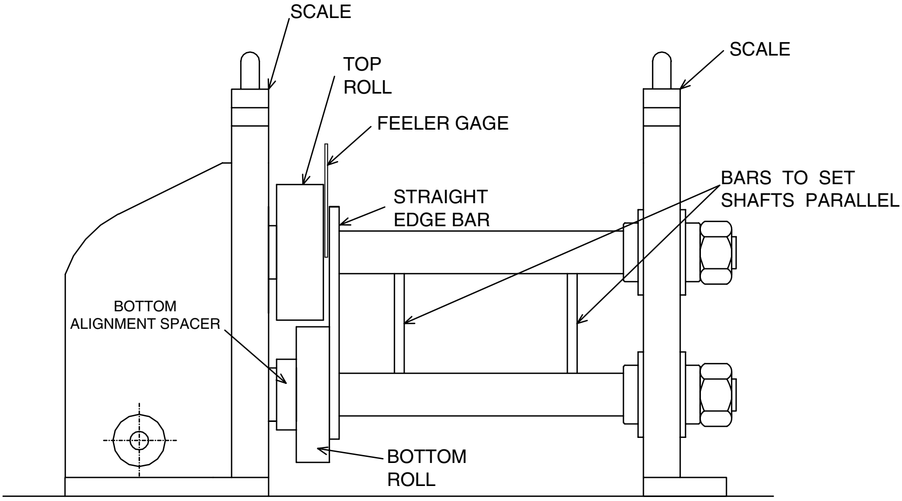


FIGURE 10.34 One method to check the (mis)alignment of the top shaft shoulder.

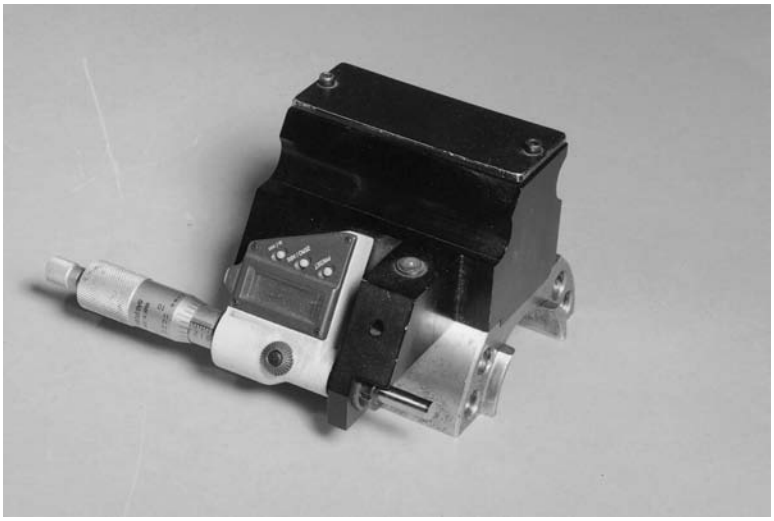


FIGURE 10.35 Shoulder alignment checking instrument.

the tools can be placed in storage. This will eliminate unpleasant surprises caused by a dull die, after the rolls have been installed for the next run. The same procedure can be applied to the prepunching and other dies.

10.3.11 Spare Parts

Some components, parts, or tools break or wear out more frequently than others. To avoid annoying downtimes and possible removal of all the installed tools, it is recommended to keep those spare parts in stock. Most equipment suppliers provide a recommended spare part list. The list can be modified and updated later, based on the user's experience. The extent to which spare parts must be stocked depends on how critical the downtime is. For example, for a roll forming mill, the company may keep

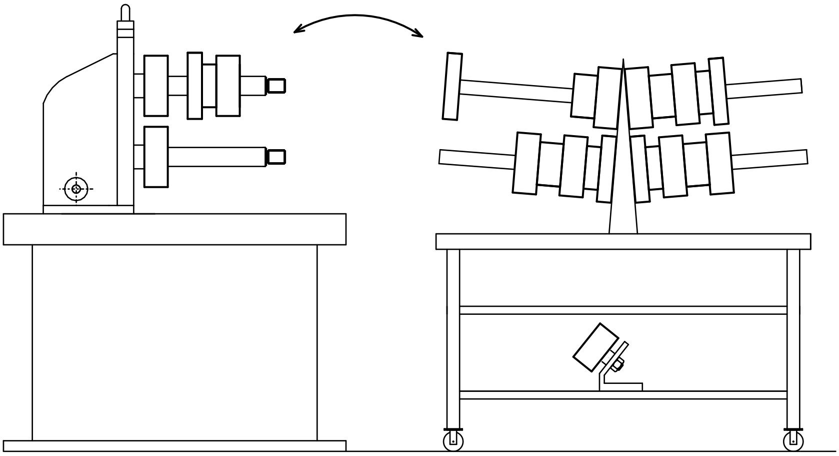


FIGURE 10.36 A typical roll storage cart.

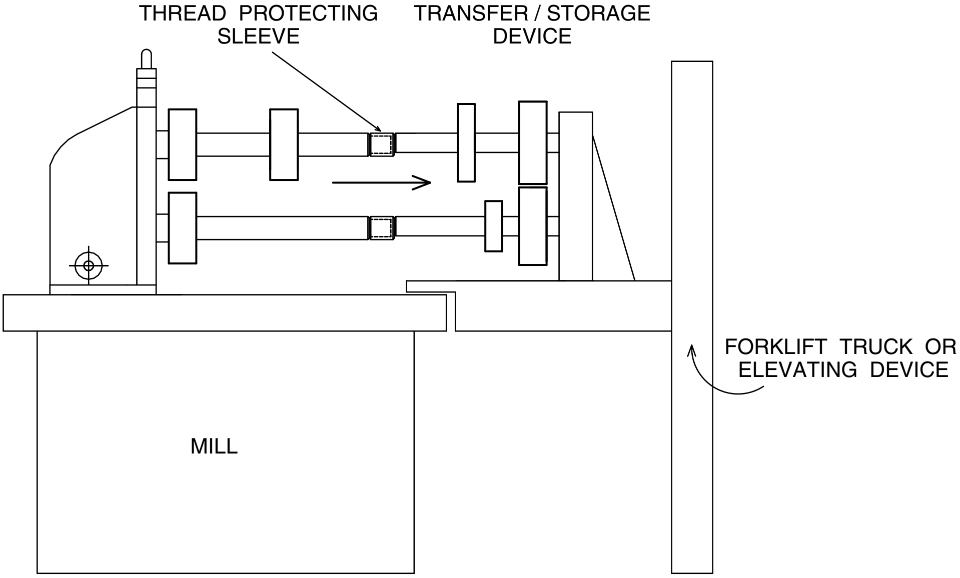


FIGURE 10.37 Power-lifted roll storage device for heavy rolls.

two cone bearings and one needle bearing in stock among other parts. Other plants may add a top and bottom shaft. The shortest downtime can be achieved when a complete spare stand is ordered with the mill.

Too few or no spare parts will create production problems. On the other hand, carrying too many spare parts is expensive. Experience and proper maintenance planning will lead to the optimum spare part inventory.

To minimize the inventory costs and make parts available, it is suggested to standardize as many components as possible. For example, a company can specify to its suppliers that they install a certain brand of microswitches and other electrical, pneumatic, or hydraulic components. This policy will reduce the spare items carried in the inventory and will assure that components are of approved quality.

10.4 Troubleshooting and Trouble Prevention

10.4.1 The Root of Troubles

To efficiently manufacture the right quality and quantity of products, the plant must have:

- The right product to be manufactured
- The right material to be formed
- The right equipment, tooling, and work environment
- A knowledgeable and motivated workforce

It is not realistic to expect that a plant can meet all four conditions all the time. However, the lack of one or more of the above prerequisites will most likely lead to problems and the plant will not be able to manufacture the right quality or quantity of products in time. The success of a manufacturing organization depends on how efficiently it can prevent troubles and how quickly it can solve problems when they arise. This is not an easy task because of the large number of influencing factors that can cause or contribute to troubles.

10.4.2 Problems Created by Design and Drawings

Most of the problems related to product design, dimensioning, and tolerancing of drawings will surface at the following times: during setup and the first production run, when changes are made to the design, drawing, or material specification, and when equipment and tooling are modified or operators are replaced.

Manufacturing can be made unnecessarily difficult by bad design and drawing habits or incorrect product specification such as:

- Not following the practical guidelines when designing products for roll forming (for design guidelines, see Chapter 9).
- Accepting orders beyond the capacity of the equipment in the plant, in terms of blank width, material strength, surface quality, and so on.
- Attempting to form thicker material than the rolls were designed for. Rolls are designed to accommodate a specified maximum material thickness plus thickness tolerances. For example, if the maximum material thickness shown on the product drawing is 0.060 in. (1.5 mm), then the rolls are designed for 0.060 + 0.003 in. tolerance = 0.063 in. (1.6 mm) material thickness. Attempting to form a 0.075-in. (1.9-mm) thick material with these rolls will result in an inferior product, waviness, broken tooling, or bent shafts.

  It is also not possible to use the above set of rolls to form 0.060-in. (1.5-mm) thick metal with a 0.010-in. (0.25-mm) thick vinyl coating. The total thickness of this coated material is 0.070 in. (1.8 mm), which will not fit into the 0.063 in. (1.6 mm) roll gap. In addition to the previously mentioned possible problems, the vinyl coating will be “chewed off” the material.
- Materials that are too wide will not fit into the entry guide, the rolls, or the mill.
- If the material is thinner than the minimum thickness for which the rolls are designed, then the tooling or the mill will not be damaged, but it can cause change in the cross-section, larger springback and waviness.
- Materials with sensitive or high luster surfaces have to be formed with tooling specially designed for them. These rolls must also be well maintained. Rolls should not be chipped or cracked, and the polished surfaces should have no “pick-ups.”

  Rolls designed for forming uncoated and galvanized steel may not be suitable for prepainted steel. Similarly, rolls designed for prepainted steel may not be suitable for forming high luster aluminum or stainless steel.
- If a roll set designed for mild steel with an r/t ratio = 1 is used to form high strength material, the product will have increased springback or the product might crack at each bend line, the shafts may deflect too much and the equipment could be damaged.

- Most coatings will crack if they are formed to a smaller-than-recommended bend radius.
- The product length can be incorrectly specified. Products that are too long may not fit onto the runout table or they cannot be handled. Precut products that are too short may not be able to pass through the roll forming mill. In a postcutting operation, the minimum length is usually restricted.
- Products are frequently copied from competitors or product designs are acquired through acquisition or licensing agreement. Even if a company has a mill with the same number of passes, the same shaft diameter, and roll space as the original manufacturer of that product, it is not certain that the plant will be able to form the product to the specifications. Other parameters such as the horizontal distances between passes, mill characteristics, the cutoff press, and other influencing factors have to be correct in order to produce the right product.
- It is usually not possible to roll form a product to tighter tolerance than in the past production runs while using the same tooling, equipment, and speed. Occasionally, the plant can manage better length tolerances, at a lower speed and a higher scrap rate.

Although the above-mentioned problems occur frequently in roll forming plants, all of them can be prevented with proper screening of the design, drawings, and tolerances before an order is accepted.

10.4.3 Problems Created by the Material

Let us assume that a plant with good equipment and properly set up good tooling is roll forming a good-quality product. Once production commences, all products would be within the specified tolerances and quality without adjusting the equipment if the material were perfect. However, perfect material does not exist. Fluctuation in material thickness, width, mechanical properties, and surface quality (coating), as well as deviation from straightness and flatness and other properties will influence the product quality. Therefore, the operator must adjust the machine to compensate for all these material imperfections.

Commercial tolerances on the materials are generally quite loose. Variation of the material properties can be so wide that it is impossible to compensate by adjusting the equipment and tooling. In such cases, the product cannot be manufactured within the required tolerances. To prevent this possibility, manufacturers often specify tighter than the standard tolerances for material thickness and width. However, they frequently overlook the adverse effect of the fluctuation between the minimum and the maximum yield strengths, and accept the excessive but still within the standard camber in the strip.

Fluctuation in thickness, width, and camber can be checked easily in the plant. However, it is more difficult to detect, check, and measure the fluctuation in the mechanical properties and changes in the metallurgical properties, both of which influence flatness and straightness. Owing to the intricacy of determining these factors, material is frequently thought to be the cause of problems that could actually be originated by the equipment, tooling, or incorrect setup. The simplest method to determine whether or not the problem is caused by the material is described in Section 10.4.7 (“Proof Coil”).

10.4.4 Problems Caused by Equipment

Inevitably, every plant will have problem(s) with its equipment. The roots of the problems, in most cases, can be traced back to the following:

10.4.4.1 Equipment

- The capabilities of the available equipment are inadequate for the job; either the equipment has been improperly specified or the company failed to select the right supplier.
- The equipment is not properly maintained. Most people have their car serviced regularly, but they do not apply this rule to roll forming mills. Many companies do not have a preventive/predictive

maintenance procedure. Even when the maintenance is finally scheduled, it is often postponed because of urgent orders or production delays caused by lack of maintenance. In these plants, attention is paid to the equipment only when it breaks down.

- Even properly selected and well-maintained equipment can break down if it is used beyond its capacity or abused by the operator.

10.4.4.2 Roll Forming Mills

The most common problems with roll forming mills are:

- Misaligned shaft shoulders
- Bent shafts
- Lack of adequate lubrication

Other frequent problem areas are:

- Poorly designed entry guides
- Difficult-to-adjust straighteners
- Inaccurately aligned side-roll stands
- Worn-out bearings.

10.4.4.3 Uncoilers

Uncoilers usually present only a few problems.

The most common problems with uncoilers are misalignment; the mandrel of the uncoiler is not perpendicular to the direction of the strip travel.

Usually problems with brakes and other components can be easily prevented.

10.4.4.4 Presses

Good-quality and well-maintained presses have a long service life. Nuts on the posts (resulting from a design fault or inadequate installation) sometimes get loose. In mechanical presses the incorrect timing of clutch and brake engagement/disengagement or liner wear can create problems.

As with all presses, the electrical, pneumatic, and hydraulic components have to be kept in good operating condition.

10.4.5 Problems Caused by Tooling

Tooling is the most frequent cause for complaint in the industry. The main reason for the complaints is that every new section requires a new set of tooling which has to be designed, set up, and tested. Once the tooling works properly, the subsequent problems are usually related to poor setup or incorrect applications. Roll wear creates much fewer problems than tooling wear in most other metal forming processes. Good tooling with good lubrication will last a long time. Rolls can also be recut, especially if the original tool drawings, updated after setup tests, are available.

Prepunching and cutoff dies usually have a good service life, but periodical regrinding is required.

10.4.6 Troubles with the Know-How of the Workforce

Inadequately trained operators and maintenance personnel are the major shortcoming of the industry and a very common source of roll forming problems. Very few companies have regular, good training programs for their operators and maintenance personnel. Some companies incorrectly keep their operators as "button pushers" and all other work is carried out by the overloaded setup personnel. This hinders productivity, and fails to satisfy and motivate the operators. At other plants, the operators are requested to set up the tooling without proper training and good setup charts. Lack of knowledge can lead to problems, poor quality and quantity of products, shorter equipment and tool life, and high production cost.

10.4.7 Troubleshooting

It is often difficult to pinpoint the exact cause (or causes) of product quality problems because of the many potential contributing sources. When a new set of rolls is installed, it almost always requires some minor modification to correct the usually unforeseen problems caused by the roll design. After the rolls have been modified by the supplier or the customer, it is assumed that the new roll set will be able to roll acceptable quality products.

The troubleshooting and trouble prevention details described in this section are based on the assumption that the original roll forming problems were corrected by the supplier and that since then, (especially in the last run), acceptable quality products have been manufactured.

It is strongly recommended to keep a few pieces of these acceptable quality products in store and to identify them properly for future reference. Products are rejected far too often with claims that quality has deteriorated in the last few years or since the last run. Properly stored samples can prove whether deterioration really took place or possibly customers are demanding better quality products now than before.

Roll wear usually creates deviation from the specified shape or bend radii gradually over a long period of time rather than suddenly from one run to the next. However, some of the problems and solutions described in Table 10.5 are also applicable for testing new sets of rolls.

It is relatively easy to prove or disprove whether the problems are in fact caused by the material or not. Always retain a few hundred feet (or meters) of material from a coil that yielded good-quality products. Mark the coil as “proof coil” for the specific product and store it in a separate place for future reference. Whenever a product problem arises that cannot be eliminated by applying the usual remedies (checking roll gaps, shaft straightness, etc.), get the “proof coil” from storage and, with the correct setup, run a few pieces from it. If the product made from the “proof coil” is acceptable, then the source of the problem is the material selected for the new job. If no acceptable product can be made from the “proof coil,” then the problem is caused by some other factors (equipment, tool setup, etc.). New “proof coil” can always be put aside whenever the product quality is good. Test runs with these “proof coils” can eliminate lots of production delays, problems, and arguments.

There are still many other sources that can contribute to product quality problems even if the tooling is good and the material suitable. As a result, it is frequently difficult to pinpoint the exact cause(s). The troubleshooter may face an additional challenge if all the facts are not available. For example, it is frequently claimed that no changes have been made since the last successful run. However, some changes may have nevertheless occurred, such as changes in material specification, supplier, equipment, tooling, or operator. Such changes that do not appear significant to the operator, maintenance personnel, plant manager, purchase agent, or the material supplier might contribute significantly to the problems.

Troubleshooting is like investigating a criminal case, where facts and information have to be gathered, evaluated, and conclusions drawn. However, in contrast to the criminal investigation, in roll forming, unsolved cases are unacceptable. Causes of problems that might elude most people may appear very obvious to an experienced troubleshooter but still there are times when even an “expert” is frustrated by efforts to pinpoint the source of the problem.

Figure 10.38 and Table 10.5 list several frequently observed problems, their possible causes, and the steps to be taken to find and eliminate the sources of the trouble. Again, the table is based on the assumption that the rolls produced the right quality product in the past and that they have not been damaged, recut, or replaced.

10.4.8 Trouble Prevention

Many roll forming problems and associated production delays, costly expenses, and arguments can be headed off by proper trouble prevention planning.

10.4.8.1 Product Design, Drawings, Tolerances, and Specifications

The first step to prevent problems is to train the product designers. The next step is to review carefully all the documents issued to the plant by a person who is knowledgeable in the capacity and capability of the

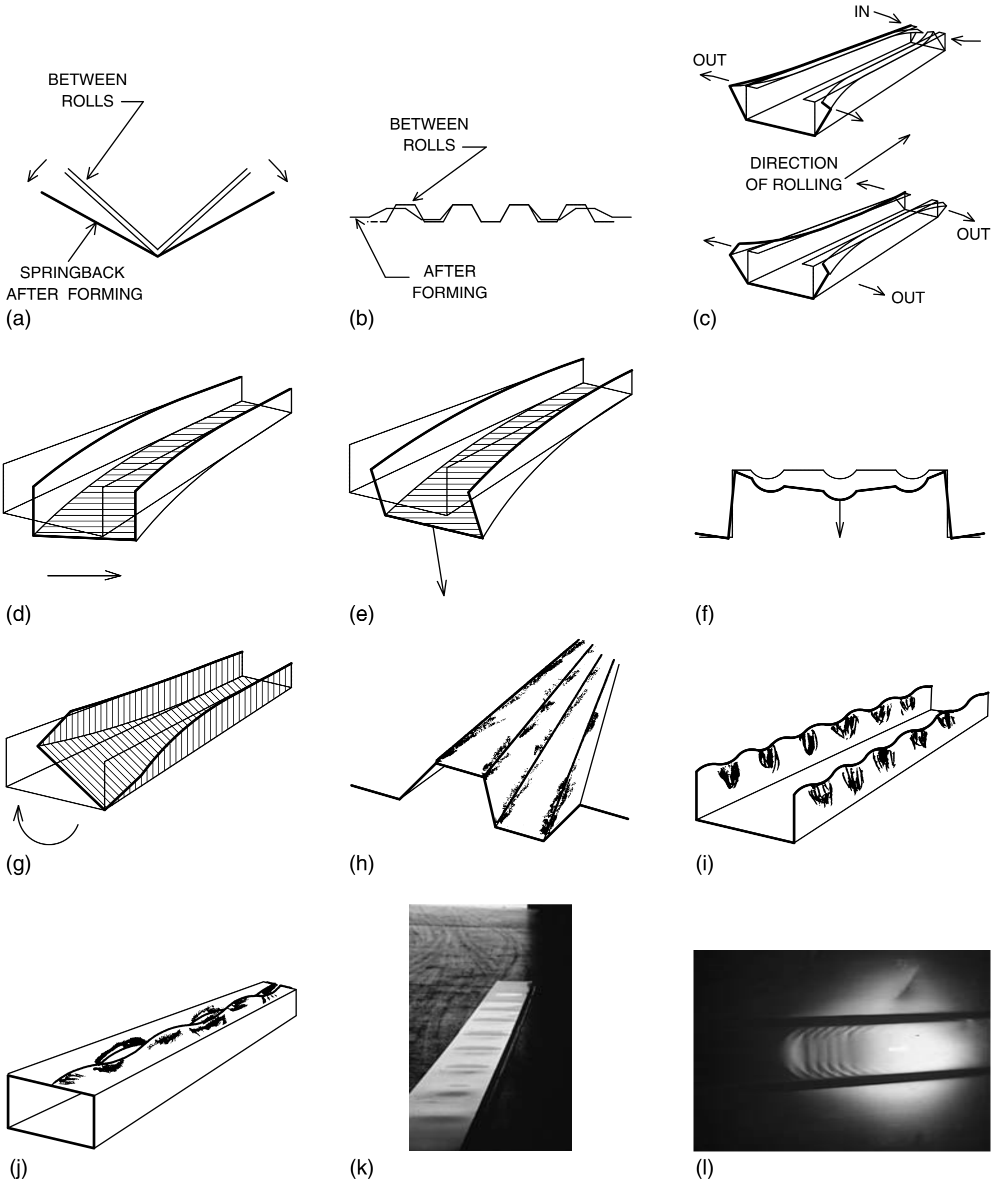


FIGURE 10.38 Troubleshooting guides (see also Table 10.5). (a) Springback; (b) Nonuniform springback; (c) Flare; (d) Camber (sideways); (e) Bow (up or down); (f) Cross-bow; (g) Twist; (h) Herringbone; (i) Edge waviness; (j) Edge waviness; (k) Center waviness; (l) Ripple; (m) Coil break; (n) Cracked material; (o) Cracked coating; (p) Peeled coating; (q) Shiny streaks; (r) Surface deficiency; (s) Surface deficiency; (t) Surface marks (repeated); (u) Gear chatter marks; (v) Uneven gap between prepunched hole patterns; (w) Hole elongation; (x) Notches off bend lines; (y) Prepunched holes off centerline after forming; (z) Hole-to-hole distance depends on the cut-to-length accuracy; (aa) Section reshaped by cutoff die; (ab) Section reshaped by cutoff die; (ac) Cutoff does not match prenotch; (ad) Hole deformed by pick-up pin; (ae) Section deformed by pick-up mechanism; (af) Section deformed by the punch stuck in the die.

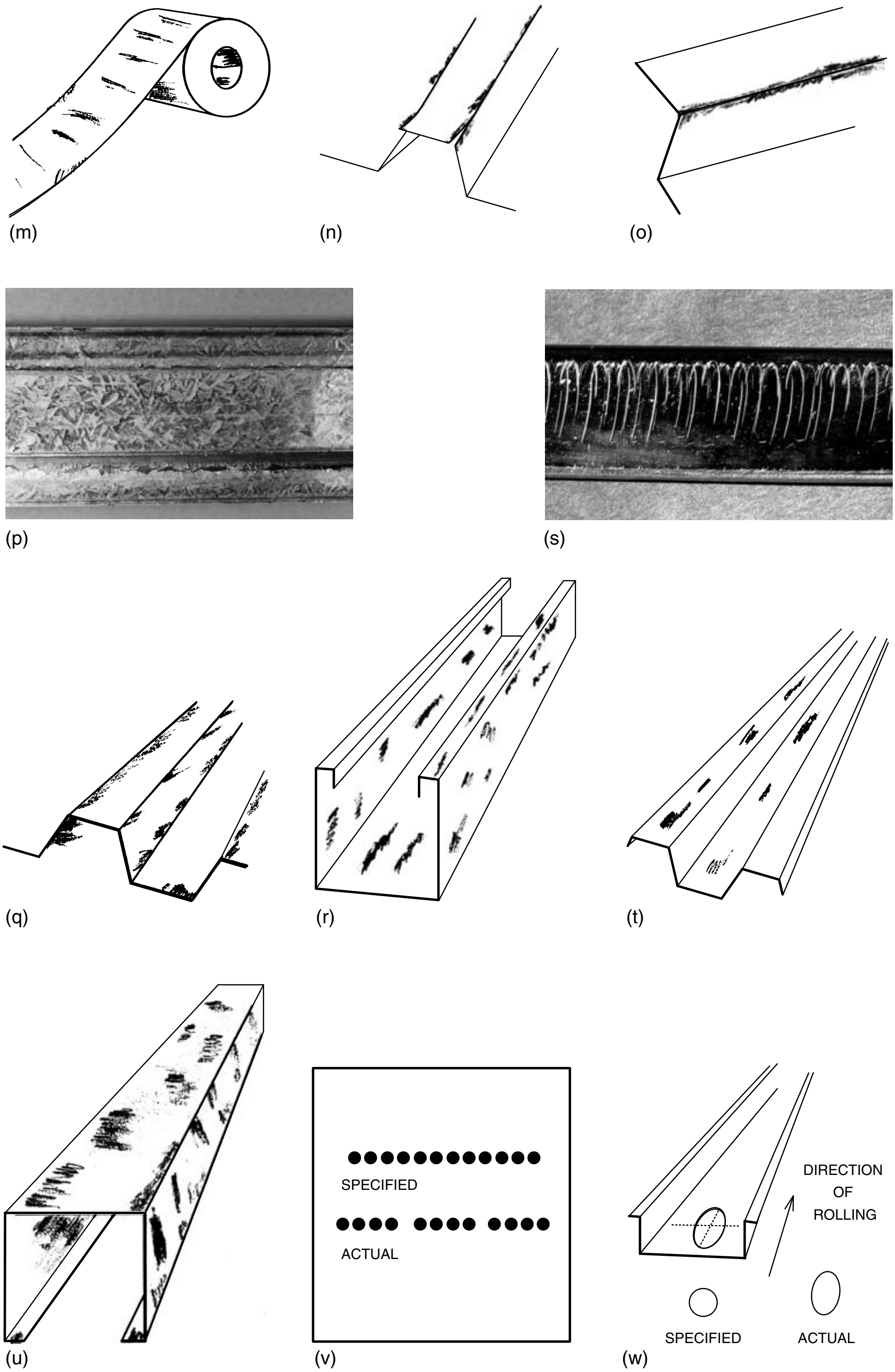


FIGURE 10.38 Continued.

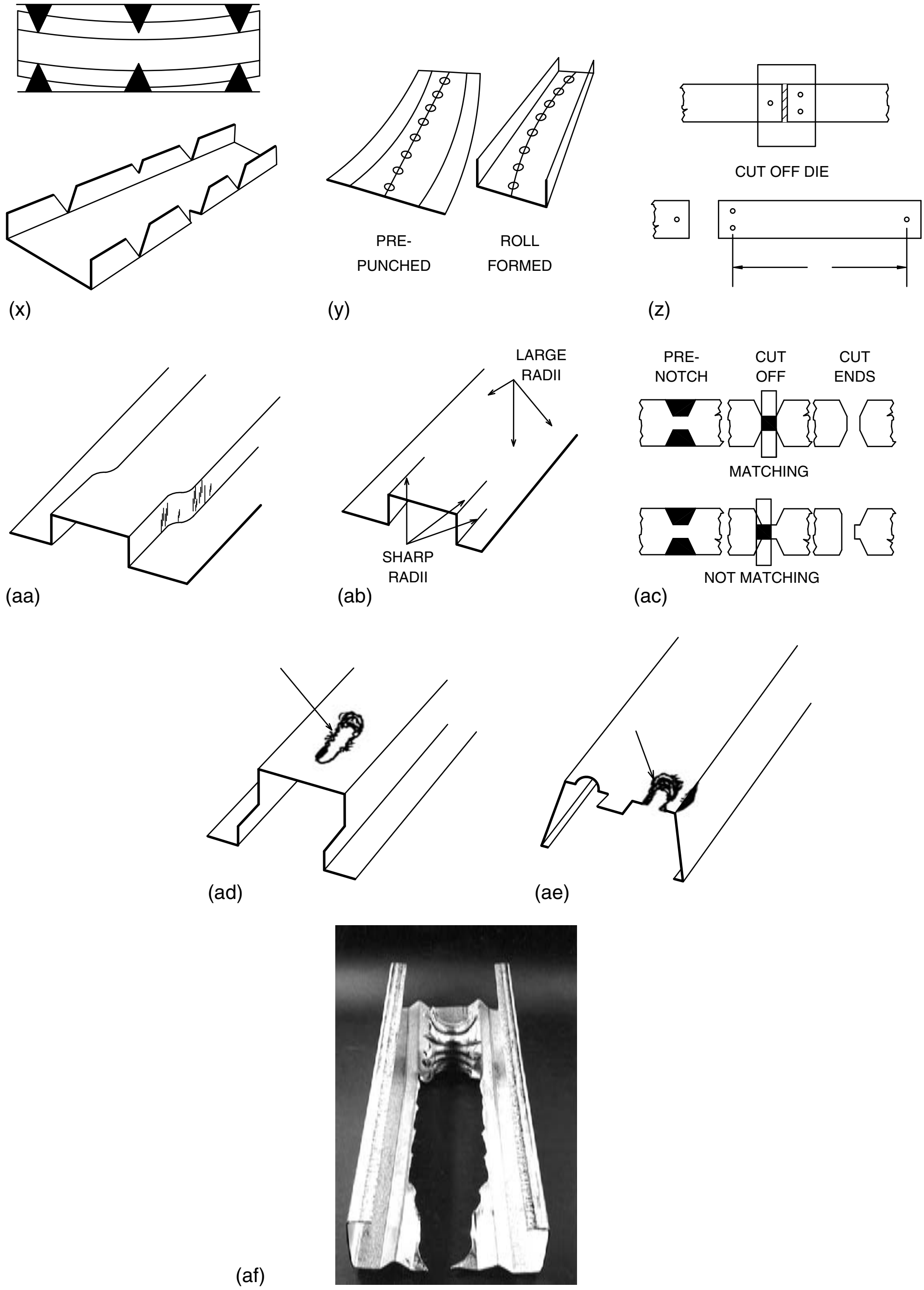


FIGURE 10.38 Continued.

TABLE 10.5 Troubleshooting of Material, Equipment, and Tooling that Performed Properly in the Past (Figure 10.38)

Problem	Possible Causes	Check/Eliminate/Prevent
Length tolerance	Length measuring unit (mechanical)	Loose components of flag switch, positive stop, pick-up pin, connecting rod, or other items. Tighten all loose nuts, or replace worn parts
	Length measuring unit (digital encoder)	Encoder wheel worn (product shorter). Adjust electronically Pick-up and dirt on the wheel (product longer). Clean it Wheel worn at one side (shaft is not parallel to the surface). Adjust Runs at an angle (skewed) to the direction of forming. Correct angle Wheel jumps when product vibrates (effect of cutoff or punching). Eliminate jumping Encoder located at the entry side and the product stretches during roll forming (product longer). Relocate encoder Shaft of the encoder wheel is bent. Replace it Electric/electronic problems
	Other electric/electronic sensor	Incorrect setup, distance, angle, location, loose installation or electric/electronic problems
	All length sensing units	Incorrect data entered by the operator (e.g., into the encoder control) Incorrect location of a mechanical device (e.g., flag switch, positive stop)
	Mechanical presses	Press does not stop at top dead center (TDC) Worn clutch or brake lining Inadequate air volume or pressure to operate the clutch and brake Problem with pneumatic accessories or valves
	Pneumatic presses	Insufficient quantity or low pressure air Problems with valves Incorrect timing or electric/electronic components Improperly set stroke Leaking hoses and other components
	Hydraulic presses	Hydraulic system problem (pressure, volume, problems with valves or other components, low pressure in the accumulator etc.) Leaking hoses and accessory components
	All presses	If the number of strokes per minute is set above the recommended maximum, then the system or individual component(s) cannot keep up with the demand
	Die rails (for flying dies)	Lack of lubrication Dirt between the sliding parts Incorrectly set sensors
	Die accelerator	Speed is not adjusted to match the speed of the strip or product Die is not completely back in the home position Loose component Can be pneumatic, hydraulic, mechanical, or electrical problem, depending on the type of accelerator

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Length tolerance (continued)	Straightener	Speed of the product can be reduced or varied by incorrectly installed or too tight straightener
	Entry guide	Can have the same effect as the straightener, especially if the product width is changing or if heavy burr creates friction in the entry guide
	Roll forming mill	Bent shaft(s) can create a pinch point and a loose point with each revolution. This will influence the speed of the product Depending on the roll design, passes set to different gaps can accelerate or decelerate the speed of the strip, which can influence length tolerance Bad bearings may act as continuous or intermittent brakes Lubrication: uneven application of lubricant can contribute to fluctuating line speed
	Uncoiler	Worn or incorrectly set brake can change the strip speed at each revolution of the uncoiler (not critical when positive stop is used) Overtightened uncoiler arms (making a triangular or rectangular shape from the round coil) can vary the line speed (not critical when positive stop is used)
	Other operations in the line	Nonuniform braking of the strip/product by the secondary operation
	Operator	Incorrect setup Incorrect setting of gap between rolls Incorrect setting of press, sensor, die accelerator, uncoiler brake
Cross-section	Where is it measured	If it is checked at the cut ends, the method of cutting (e.g., saw) or cutoff die or flare may change the cross-section (end cross-section will be different from the uncut cross-section). Check section away from cut ends or notches
	Setup	Check setup against the proper setup chart Check roll gap at each pass Check tracking of bend lines See also “Springback” and “Flare”
	Roll forming mill	Incorrect shoulder alignment (it is very frequently the source of the many problems) Check for bent shaft. Bent shafts usually create repeatedly changing dimensions where the change happens at distances of about every three times the roll diameter
	Tooling	Wear does not create sudden change in the cross-section unless worn, chipped or broken tools are recut or replaced Wear usually (and slowly) increases bending radii
	Material	Change in the mechanical properties (see also “Springback”) Significant change in material thickness Cross-bow in the material (especially in heavy gages) Deviation from straightness or flatness can induce waviness Waviness can influence angles (depending on where is it measured)

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Cross-section (continued)	Entry guide	Improperly set entry guide opening If it is too wide, then the material can wander between the operator and drive sides If the opening width is correct, but the entry guide is positioned too far to the operator side or to the drive side of the mill
	Straightener	Incorrectly set or remachined straightener can deform cross-section
Springback [Figure 10.38(a)]	Mechanical properties of material	Check material Change the degree of overbending Check the setup with another (possibly softer) material
	Setup	Check the setup of the overbending rolls Check the gap between all rolls; too big gap can create a false impression of springback Check roll pressure at the bend lines If there are scoring rolls in the first passes, then check the setup and wear
Nonuniform springback [Figure 10.38(b)]	Material	Roll designer usually incorporate this roll forming peculiarity into the roll design when forming the outside ribs of wide panels. Nonuniform springback can be caused by roll forming considerably higher strength material than the rolls are designed for, or when roll forming considerably thinner material with relatively large bending radii
Flare [Figure 10.38(c)]	Rolls and roll setup	Too much bending at one or more passes More gentle forming reduces flare Slight overbending and then "opening up" to the right angle reduces flare Locating side-roller stand in different locations can influence flare In some cases, "compressing" the bend lines (applying pressure on the legs of a "U" or "C" channel) can change the internal stresses, thus reduces flare (reported several times but not fully researched) In some cases, forming the bend lines in the conventional way, but rebending them to a smaller radius in the last forming pass Changing the gap and/or degree of bending in the first passes sometimes will change the amount the lead end of the strip "dives" downward (or upward) from pass to pass. This "dive" down (or up) may have some connection with the flare of the finished roll formed product Recutting the rolls to a slightly different shape
	Equipment	Forming the section with another mill having different horizontal distances Changing from post- to precut influences flare
	Cutoff die	Method of cutoff will not influence flare. However, if the cutoff die includes a change in the cross-section (e.g., swedging), then it can reduce the flare (at one end of the product)

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Flare (continued)	Material	Material with higher yield and tensile strength and lower elongation will flare more (see also "Springback")
	Flare reducer	A few companies employ "edge straightener" to reduce flare. Incorrect setting of this flare reducer can increase the flare
Camber [Figure 10.38(d)]	Camber in the material	Flip over coil or strip and run again: If camber in the finished product remains in the same direction, then it is not caused by the material If after flipping the coil over, the camber in the finished product is facing the opposite direction, then the material causes the problem
	Slitting induced camber, burr, or waviness (along one edge of the strip)	Flip over coil or strip: same procedure as above
	Misaligned equipment	Check the alignment of the uncoiler, press(es), roll forming mill and all other equipment in the line
	Uneven (asymmetrical) serration or embossment	Check for uniform embossment depth at both sides. A small tilt of the embossing roll can induce camber or straighten the strip
Bow [Figure 10.38(e)]	Material	Bow (coil set) in thick or high strength material
	Slitting	Avoid burr or waviness at both edges
Camber or bow	Operator	Check tool setup against setup chart Check shoulder alignment of the mill shaft if required Check roll gap at each pass Check side-roll pass setup Check height and angle of the side-roll stands Check the perpendicularity of side-roll stands (90° to the product travel) Check roll pressure at one side (or both) of the strip Check for shinny marks or wavy edges at one side (usually close to, or at the outside edge of the cambered products or both sides if product bows)
	Bad straightener setup	Run product as straight as possible without straightener, then install straightener to make the final correction
Cross-bow [Figure 10.38(f)]	Material	Thick material with cross-bow Flattener can reduce or eliminate cross-bow
	"Stretched-in" groove	Cross-bow in light material can be reduced by reducing the depth of the stretched-in groove but this will change the dimensions
Twist [Figure 10.38(g)]	Twist in the material	At some equipment in the line (e.g., strip accumulator), occasionally a 90° twist is made in the strip in a short distance. The twist may or may not yield twist in the finished product. Check by passing a strip without twist through the mill
	Excessive twist in thick material	Unusual situation, but it can happen Check setup with a straight, not twisted strip

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
	Camber in the material	Camber in the strip and product corrected by the straightener may induce twist; flip over a strip to see if the product twists in the same direction or in the opposite direction (clockwise, counterclockwise)
Twist (continued)	Camber caused by other sources	Camber induced by other sources (see "Camber") and corrected with the straightener may induce twist Try to eliminate camber in the product before entering the straightener
	Strip with wavy edges	Wavy edges mean that edges are longer than the center. It has the same effect as the previously mentioned two items and can yield twisted product
	Bad straightener setup	Run product as straight as possible without straightener, then install the straightener to make the final correction
Twist [Figure 10.38(g)]	Cross-embossing at the center	Embossing the center part of a panel across the direction of roll forming shortens the center. If the center part is shortened and the edges are longer, then, after roll forming, the product will twist. Twist will increase with increased cross-embossing depth, or when the material is thinner, or the material has higher strength and lower elongation
	Too much pressure at both edges	Too much pressure elongates the edges of the strip which will cause twist
Double-bend lines	Misaligned tooling	Check roll setup (location of rolls and proper gaps) Check shoulder alignment
Edge waviness [Figure 10.38(i) and (j)]	Material	Material with wavy edges will most probably yield products with wavy edges Camber in the material can create waviness at the edge of the product corresponding with the "outside" of the camber. This can be checked by flipping over the coil and to see whether the waviness remains on the same edge or moved to the other one
	Setup	Too high pressure on the edge(s) will elongate the material and will yield wavy edges in the finished product Straightener correcting extreme camber, bow, or twist caused by incorrect setup can induce waviness
	Incorrectly adjusted flattener	Incorrectly set flatteners stretching one or both edges of the material elongate the edge of the material and create edge waviness
	Incorrect equipment alignment	Misalignment of the uncoiler, press(es), mill, and other equipment in the line causes camber, which, after straightening, can prompt waviness at one edge
	Bent shaft	A bent shaft, especially in cantilevered mills, will change the angle of bending which will appear as waviness. The distance between the maximum waviness will be about three times the roll diameter
Center waviness [Figure 10.38(k)]	General	Center waviness (oil canny appearance) usually occurs when the center (wavy) segment of the product is longer than the edges. This length difference can be caused by many factors

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
	Material	Coil had wavy center: Roll forming will not remove waviness, but ribs can dissipate (appearance will be somewhat better)
Center waviness (continued)		If material thickness is reduced, the product will be more prone to center waviness Waviness may not show up in short products (about 10 ft or 3 m), but longer products will display more pronounced waviness Identical waviness will appear more pronounced in high luster (shiny) surface, and will be less visible when the surface is dull Corrective leveling of the coil before roll forming makes the edges longer. If correctly applied, in many cases, waviness of the center part will be minimized or will disappear Tension leveling of the coil will not help, frequently it makes the appearance of the product worse The simplest way to prove or disprove the cause of waviness is to roll form product from the "proof coil" in the same setup If center waviness is dominant at one side of the product, then it could have been caused by camber in the coil. Flip the coil over and run a few pieces. If waviness appears at the other side, then it is caused by the camber in the coil (or waviness at one side only). If the waviness appears at the same side, then it is caused by other factors Quality of slitting can influence center waviness Low strength material often has a higher tendency to be wavy than high strength material The steel making technology, metallurgical properties, and residual stresses in the coil have strong influence on center waviness
	Product Design	The wider the flat surface between the bend lines, the more prone it is to waviness (high flat width:thickness ratio) Large radii at bend lines will reduce and very sharp bend line will increase the tendency of waviness Holes and notches will reduce the buckling strength of the flat section, hence increase waviness Stiffening embossment and increasing buckling resistance will diminish the waviness
	Equipment and tooling	Bent shafts can induce waviness Misaligned equipment, misaligned rolls and side-rolls will prompt waviness Incorrect setup, nontracking bend lines can cause waviness Excessive pressure on the flat section will reduce the thickness of the material and create waviness
Herringbone and ripple effect [Figure 10.38(h) and (i)]	Setup	Check setup, especially the tracking of the bend lines from pass to pass
	Material	In borderline cases, the thinner the material, the more likely the product will have ripples

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
		The relation between the moment of inertia of the cross-section and the contraction of panel width can effect herring bone defect
Herringbone and ripple effect (continued)	Equipment	Misaligned shafts Refurbished or modified mill where the shafts may be parallel but not exactly perpendicular to the direction of the strip travel create ripples, waviness, and other problems in the finished profiles
Coil break [Figure 10.38(m)]	Uncoiler	Uncoilers with narrow, overtightened leaves will "break" the coils from edge to edge, in repeated straight lines. Coil breaks can be eliminated by using at least four wide leaves in the uncoiler and less pressure To prevent coil break, the large hydraulic pressure required to hold large diameter coils should be reduced when the coil has only a few wraps close to the inside core
	Recoiling	Incorrect recoiling by the coil supplier can also result in coil breaks Almost all coil breaks can be eliminated with flatteners installed after the uncoiler but the best is to prevent them
Cracked material (at bend line) [Figure 10.38(n)]	Material has higher strength than the tools are designed for	Yield strength of the material is higher (and elongation lower) than the rolls are designed for Material work hardens quickly Textured embossment of coils results in work hardening. Roll forming these embossed material usually does not cause cracking but additional operation such as curving may crack it Note: Hydrogen embrittlement, caused by galvanizing or aging of steel, does not contribute to edge cracking Similarly, the direction of shearing (rough breakthrough) which is critical in brake forming does not appear to influence roll forming
	Incorrect tool setup	Check roll setup against setup chart Check roll alignment (and shaft shoulder alignment) Check tracking of bend lines. If rolls are not properly aligned, a bend line can be straightened out, then bent again. Bending back and forth can crack the material Check roll gap. Hard "pinching" of the bend line can harden material Scoring roll cuts too deep in the material or is on the wrong side of the strip (should always be inside of the bend line) Section formed from high strength material was excessively overbent and then "opened" up
	Material	Deep embossing, such as creating "wood imitation" doors, often requires drawing quality steel. Owing to material or die problem, the embossment may crack but the crack is not at the bend lines. This is a drawing (embossing) and not a roll forming problem Dimples, louvers, and other bent and stretched shapes may crack because of the mechanical and metallurgical properties of the material

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Cracked material (at bend line) (continued)	Equipment and tooling	Misaligned male and female rotary embossing tooling can create undue high stresses resulting in cracks Embossing with press die: incorrect tool setup can crack the material Sharp corners of punched angular holes can initiate cracks because of high stresses during roll forming, especially at or close to the bend lines, or at the outside fiber of curved (swept) products
Cracked coating [Figure 10.38(o)]	Material	Quality or thickness of coating is changed; roll form product from other coil (possibly from the already proven "proof coil") Material is substantially thicker than before; the thicker the material, the higher the stresses will be at the outside fibers Thick laminate also increases the total thickness of the product. It will have the same effect as substantially thicker material described above Material is very hard. Even if the material does not crack, the coating may show hairline cracks
	Tooling	If any or all of the rolls have been recut to a sharp radius, or a sharp radius is created by a side-roll stand or straightener
	Setup	Incorrect alignment — bend has been straightened and rebent Painted or laminated coating cracks at sharp bend lines. Cracking often can be eliminated by preheating the coil just before it enters into the mill using electrical or gas heaters, hot water "bath," and so on If prepainted material has been stored outdoor (or transported) at a very low temperature, and is processed without warming it up, it may crack
Peeled, scraped off coating, and fines [Figure 10.38(p)]	Coating quality	When zinc, paint, or laminate is peeling at the bend lines or any other parts of the product, it is caused by poor quality coating. It cannot be eliminated by roll forming. Solution: change the coil Crude test: scratch with a coin the paint of the coil that creates problem, and with the same force, scratch the paint of a good coil. Compare the amount you can scrape off and the scratch marks This method is not concrete proof for good or bad quality coating, but can provide an indication of quality when comparing coatings
	Tooling	When scraped off paint (or laminate), powder or fibers are collected after a pass, then check the roll setup and gaps, check the mill and product design again. If scraped off coating still appears, check side-roll passes, entry guide, and possible places which may scratch the paint off the product Check product for scratch marks (see below) Check slit edges (see "slitting" below) Check rolls for pick-up (roll surfaces should be smooth) If rolls have been recut, rough roll surface may crate problem

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Peeled, scraped off coating, and fines (continued)		Too narrow entry guide or trapping on the rolls can "shave off" coating or precut material Check strip width. It must not be wider than the specified maximum
	Slitting	Bad slitting frequently leaves metal fines or fine, cracked, pulverized material at the slit edges which will be deposited on the mill. After cleaning the mill bed and tooling, clean the edges of the strip before it enters the mill with a "rag." Contact the slitter if the rag picks up undesirable fibers or fines
	Lubrication	Check the lubricant used in forming Check the tank and the filter in the recirculating system In critical cases, install open cell foam blocks, pushed against the top and bottom rolls to remove fines
Surface scratch marks (straight) [Figure 10.38(r)]	Entry guide, side-roll stand, straightener, cutoff die	Long straight scratch mark on the finished product. It is relatively easy to trace it back to a sharp edge or corner causing this defect
Surface scratch marks (arc) [Figure 10.38(s)]	Pick-up on roll, chipped roll, cracked roll	Arc (circular) types of scratch marks on products on the nonhorizontal legs or webs are most frequently caused by "pick-ups" on the rolls. The pick-up is usually zinc or other metallic material transferred and fused to the roll by combination of pressure and friction clean the rolls prevent pick-up by applying proper lubricant and assure proper gap between rolls Polished rolls have lesser tendency to "pick-up" foreign material than rolls with rough surface Chrome plating of the rolls are most often unnecessarily recommended. In some cases, it helps to eliminate or minimize pick-up, but in most cases, the polished, smooth surface of the plated rolls is more important than the chrome on the surface If the marks are caused by chipped (or cracked) rolls, then a good solution is to replace the chipped (or cracked) rolls. A quick, short-term solution is to grind off the sharp edges around the chipped roll edge
Surface scratch or mark (repeated) [Figure 10.38(t)]	Same as listed under "Arc" type scratch marks	It appears at intervals of approximately three times the roll diameter
	Bent shaft Other rotating tools, side or straightener roll, secondary operation rolls, and so on	It is usually easy to trace back to the roll or to other rotating component
Shiny marks [Figure 10.38(q)]	Material	Some material, such as Galvalum-coated steel, dull stainless steel or some dull painted surfaces will show shiny pressure marks along the bend lines, even when minimum roll pressure is applied. These marks are due to the surface characteristics of the strip (metal or coating) and usually cannot be eliminated
	Roll setup	Too much roll pressure (or insufficient roll gap) will create shiny marks in a narrow strip in the full length of the product. This is the most frequent cause of shiny marks. The location of large pressure can be easily traced back to the pass causing it while the product is still in the mill

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Shiny Marks (continued)		If the shiny marks are intermittent at the interval of about three times the roll diameter, then most probably the shaft is bent or the bore in the roll is off center
	Nonrotating rolls	If a nondriven shaft or a side-roll is stuck (not rotating), it can create long shiny marks
	Supporting tables, guides, and other components	Entry tables, entry guides, side-roll stands, straighteners, cutoff die, and other components rubbing against a sensitive surface can cause shiny surface streaks. Relieving the pressure usually eliminates these marks
	Stop and start	Frequently, when the line is stopped and is restarted, due to the inertia of the strip and coil, the rolls will slip momentarily on the product. This slippage leaves narrow, shiny marks across the strip
	Uncoiler	If the uncoiler brake is not tight, a loop will develop between the uncoiler and the mill whenever the line stops. Every time when the line starts and the loop "straightens," the inertia of the coil will momentarily stop or reduce the speed of the strip engaged in the mill. This momentary change in speed will make the rolls slip on the material and will create a shiny mark across the strip at the contact surfaces with the rolls
	Gears	The teeth of the gears, which are squeezed closer than the permissible minimum, grind into each other, generating noise and vibration. The gearbox vibration can be transmitted onto the products as narrow, shiny marks across the strip (called "gear chatter")
Location of prepunched holes, cutouts (in longitudinal direction) [Figure 10.38b(v)]	Feeder or pick-up	Fluctuation in the feeding distance between repeated hole patterns will show up in the finished product
	Tool setup	The accuracy of tool setup of adjustable dies and separately installed die sets has an obvious effect on the hole pattern of the finished product If the distance between the die sets is incorrectly set, then it will be consistently show up in the finished product; thus makes it easy to track back the source of the problem
	Roll setup	A frequent reason of change in the hole, notch and other cutout locations is the roll setup. Too high pressure exerted on the material will make it thinner and longer. The distance between holes, cutouts (in the longitudinal direction) will increase Thin material can stretch between operations and between passes, especially if the incremental increase in roll diameters are relatively large
Location of prepunched holes, cutouts (across the direction of rolling) [Figure 10.38(x) and (y)]	Precut strip or coil	Change in the bend line location changes hole location A modification in the method of guiding and locating precut strips or coils in the punching die can influence the hole locations in the finished product
	Entry guide	If the entry guide position is moved, the holes will be at incorrect distance from the bend lines

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Location of prepunched holes, cutouts (across the direction of rolling) (continued)	Camber in the strip	Camber in the strip has an influence on the hole and notch locations. The longer the hole pattern per hit and the larger the camber, the more significant the effect
	Strip width	Too narrow strip can "wander" back and forth between guides in the prepunching die, the mill entry guides, and between the traps in the rolls. The distance the strip wanders influences the location of holes from the bend line and edges
	Setup (cross-section)	As a result of incorrect setup, the section can be out of tolerance (e.g., too shallow) and the bend lines will be at different position. This will influence the holes to bend line distances
	Material thickness	The bend line of thicker material takes more material than a thinner one. Therefore, the hole location tolerance across the strip should include the difference between the arc lengths of different thicknesses at each bend line. Theoretically, for each thickness, a separate punching pattern is required, but in most cases, only one die is built. As a result, an unexpected change in the thickness can change the hole locations in the finished product
Location of postpunched holes and notches [Figure 10.38(z)(26)]	Method of cutting to length	The distance of holes from the cut edges is a function of the cut-to-length accuracy (for additional details, see "Length Tolerance" in this table and Chapter 3)
	Punches in the cutoff die	The distance between the holes punched at the front and the tail end of the product depends on the length accuracy of the cutoff (see above)
	Separate die sets	Holes punched by adjustable die sets or individual punches installed in the press will be influenced by the accuracy of the setup
Embossments, louvers, lances	Wrong location (not within tolerance)	See comments above in "Location of Pre- and Postpunched Holes and Notches"
	Too shallow	Punches are worn Punches have been reground and installed without compensation for their reduced length Press stroke is incorrect (if stroke is adjustable) Press tonnage is not sufficient (insufficient air or hydraulic pressure etc.) Yield of material is too high (press tonnage is not sufficient) or springback is excessive Material is too thick (press tonnage is not sufficient)
Embossments, louvers, lances		Depth is correct after the press operation but the protrusions are "squashed" back in the mill because the roll space is too small The height of protrusions can be reduced by side-rolls, guides, or by the too small opening in the cutoff die Protrusion height can be reduced by the method of finished product handling (bundle weight), shipping, or assembly equipment
	Too deep	Replacement punches are too long, or shims under punches (if any) are too thick Press stroke or die stops are incorrectly set

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Embossments, louvers, lances (continued)	Cracked	Properties of the material are different. Test the setup with a piece from the "proof coil" Punch penetrates deeper than specified Punch and die are "slightly" misaligned Press stroke is too long
Section deformed by the cutoff die [Figure 10.38 (aa and ab)]	Section	The roll formed section is not within the specified tolerances. Check setup or material
	Alignment	Cutoff press/cutoff die is not aligned with the mill
	Cutoff die	Loose or damaged cutoff die component(s) Incorrectly removed or reassembled cutoff die
Section stuck in the cutoff die	Section	The roll formed section is not within the specified tolerances. Check setup
	Flare	Cut ends with unusual high flare (caused by setup problems or higher strength of the material) can be caught in the die
	Waviness	Wavy section may not pass through the die clearance
	Camber, bow, or twist	Dies made for straight section may not have enough clearance to pass through products with camber, bow, or twist
	Material	Springback deforms sections. Material strength may be higher than specified Material is thicker than specified
	Burr	Heavy burr created by slitting, incorrect entry guide, roll setting or by punching can stop the product from passing through the die
	Die	Loose die segments, blades and inserts, or incorrectly reassembled die may have "steps" hindering the passage of the product After cutting, the die does not open completely. Check springs and other lifting devices Pick-up pins or other moving parts do not function properly The die is not flying exactly parallel with the direction of the product travel (not parallel to the center line). The press or rails are at an angle to the center line
	Postpunching die	Punch is broken or not lifted up Punch creates excessive burr Punch does not push the slug out of the hole Product is deformed in the die
	Press	Press is not positioned properly in the line Press centerline is not parallel with the travel of the product Press stroke is not correct Press does not have the required force. It shears through the product partially instead of cutting or punching it. Check pneumatic, hydraulic pressure, clutch, slippage, and so on

(*Continued*)

TABLE 10.5 (Continued)

Problem	Possible Causes	Check/Eliminate/Prevent
Section stuck in the cutoff die (continued)	Die accelerator and press cycle	Die speed is not synchronized with the speed of the product. During cutting, the slow die holds back the product, which may buckle or crumple in or ahead of the die. Pick-up holes can be elongated and material wrinkled The die is stopped and pulled back into the direction of home position by the die accelerator before the cutting blade or punches are disengaged Press cycle is incorrect. If it is too slow, the cutting/punching is not completed before the end of the forward travel of the die
	Straightener	The operator tries to compensate for excessively cambered, bowed, or twisted product by forcing it in the opposite direction while one end of the product is in the cutoff die. The forces created by friction can be higher than the force pulling back the cutoff die. The section traveling at roll forming speed pushes the die out of the press, actuating the emergency stop
	Welded strip joint	Incorrectly welded strip end joint can get stuck in the die. The weld can be thicker than the thickness of the material, or it is cracked
Cutoff burr	Cutoff die	Cutoff die insert is dull, require resharpening Material thickness or strength is not within the specified range Cutoff die components are loose, damaged, or are incorrectly reassembled (possibly incorrect shim used after sharpening)
Prepunching/cutoff mismatch or other problems [Figure 10.38(ac, ad, and ae)]	Pre and postpunch mismatch See comments at "Location of reprepunched holes and cutouts in longitudinal direction and across the direction of rolling" as well as in "Location of postpunched holes and notches" in this table	
	Re-prepunched holes damaged by cutoff die pick-up	Same comments as above Cutoff die accelerator or other related problems
Hole or notch deformed by the punch [Figure 10.38(af)]	Punch was not retracted in time	Press timing Die accelerator problem Punch clearance Inadequate or off-center stripping force

plant, equipment, tooling, and the work force. It is easier to discuss potential problems at this stage then to discover them later during production.

10.4.8.2 Material

To ensure good material quality for manufacturing, it is recommended to establish and use the following standards or procedures, which are specifically designed to meet the company's requirements.

- Material standards
- Standard ordering specifications
- Incoming material inspection (spot checks)
- Procedure to identify every full and partially used coil, with indication of the original coil data from the supplier
- Procedure to keep (and replenish) "proof coils"
- Procedure to investigate and to follow up material-related production and product problems

10.4.8.3 Equipment and Tooling

Specifying, selecting, and procuring inefficient, low quality equipment, and tooling is a recipe for troubles, headaches, and inefficient production for many years to come. This does not necessarily mean buying the most expensive equipment, but buying the best within the available budget. Good equipment and tooling will save substantial amount of time and money.

After the roll forming line and the tooling are installed, working properly and are producing acceptable quality and quantity of products, a proper maintenance schedule should be prepared. The maintenance work should be carried out as specified and at the scheduled time.

10.4.8.4 Work Force

The best equipment and tooling alone will not manufacture products without knowledgeable operators, maintenance personnel, and supervisors. Other personnel involved in the manufacturing, such as the purchase agent, production and inventory control personnel, engineers, and manufacturing management can also greatly contribute to, or in the case of lack of knowledge greatly retard the productivity of the plant.

Continuous hands-on training of the line operators and maintenance personnel, and providing regular updating courses for all other personnel are the key elements of successful manufacturing.

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11

Behavior of Metal Strip During Roll Forming

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11.1 Various Types of Deformations

In roll forming processes, metal strips are subjected to various types of deformation as explained below.

11.1.1 Transversal Bending

The most important and indispensable deformation for metal strips is transversal bending deformation. Transversal bending is needed to form metal strips into products with required cross-sections (Figure 11.1), and gradual forming is achieved by using a series of contoured rolls.

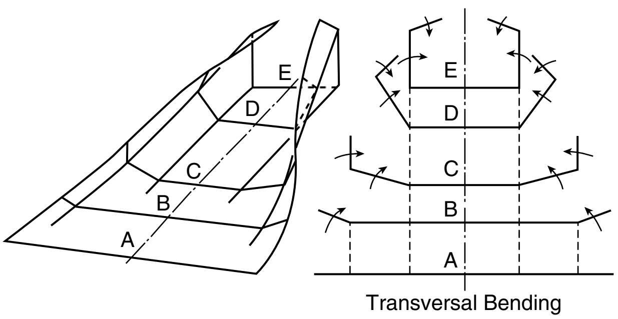


FIGURE 11.1 Transversal bending of metal strip during roll forming.

11.1.2 Redundant Deformations

Metal strips are subjected to many other deformations in addition to transversal bending. Metal strips are entered into roll forming mills either in precut or coil form, and are gradually deformed into complicated three-dimensional (3-D) shapes by a series of contoured rolls before they are finally made into products. Because of this process, various types of additive redundant deformations are induced in the metal (Figure 11.2).

The additive redundant deformations (hereinafter called "redundant deformations") are:

1. Longitudinal bending and bending back
2. Longitudinal elongation and/or shrinkage
3. Transversal elongation and/or shrinkage
4. Shear in the metal's plane
5. Shear in the direction of the metal's thickness
6. Various combinations of the above (Figure 11.2)

These redundant deformations are superimposed on the transversal bending and they significantly influence the formation of the product's cross-section and shape. Many problems, which occur in roll forming processes, are related to redundant deformations.

In order to properly design rolls, build suitable equipment, optimize processes, maintain stable operation, improve quality of products, attain high productivity, and innovate overall aspects of roll forming technology, the behavior of redundant deformations and their influence upon the product's

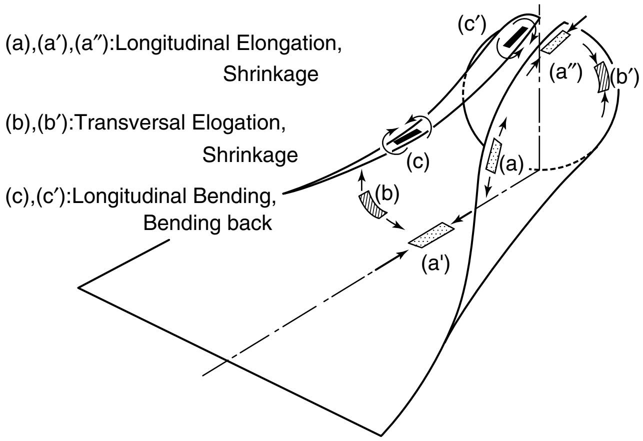

(a),(a′),(a″):Longitudinal Elongation,
Shrinkage
(b),(b′):Transversal Elogation,
Shrinkage
(c),(c′):Longitudinal Bending,
Bending back
(c′)
(a″)
(b′)
(c)
(a)
(b)
(a')

FIGURE 11.2 Additive redundant deformation of metal strip during roll forming.

shape should be systematically investigated and clarified. The investigation should cover the following subjects:

1. Cause and magnitude of individual redundant deformation in metal strips.
2. Quantitative and qualitative influence of redundant deformations on products' shapes and dimensions.
3. Effects of forming conditions, such as the mechanical properties, width, and thickness of the metal strip, the number of passes, roll profiles, roll positions, roll gaps, pass line, and the geometry of the product's cross-section on magnitude and distribution features of redundant deformations.
4. Mechanism of occurrence and influence of redundant deformations on product defects.
5. Methods to reduce redundant deformations.
6. Countermeasures to prevent product defects caused by redundant deformations.
7. Methods to maintain smooth and stable flow of metal sheets, improve quality of products, and attain high productivity.

11.2 Causes of Redundant Deformations

11.2.1 Longitudinal Elongation or Shrinkage

In roll forming processes, strips are fed continuously into forming machines and are formed step-by-step into products by pairs of contoured rolls. The strips are progressively bent in the transversal direction and their cross-sectional profile is gradually transformed to the required shape. In the process, the height (or depth) of the transversal cross-section (hereinafter referred to simply as "cross-section") of semiformed strips increases from the initial height, equal to the strip thickness, to the height of the product's cross-section. The width of its cross-section decreases from the initial strip width to the width of the product's cross-section.

This means that during roll forming, each portion of the strip shifts, moves and deforms in both vertical and horizontal directions to form 3-D curved shapes (curved surfaces; Figure 11.3). Every portion of the strip moves along the entry guide to the first rolls, then to the second rolls and on to the last rolls along the spatial flow lines corresponding to the curved surface.

Both transversal edges and the adjacent areas of the strip (hereinafter referred to as "edge portions") usually move along flow lines which are longer than those for center portions and intermediate portions. This is caused by the fact that, while the center part usually travels in a straight line, the edge portions often rise vertically and, at the same time, shift horizontally toward the center of the cross-section (Figure 11.3). Because of the vertical rising and horizontal shifting, the edge portions usually elongate, while the center and intermediate portions shrink in the longitudinal direction.

The magnitude and transversal distribution pattern of the longitudinal elongation and shrinkage are balanced to maintain an equilibrium of the longitudinal forces acting on the transversal cross-section of the strip. The longitudinal forces acting on the cross-section of the semiformed strip are equal to the sum of the longitudinal stress induced on its cross-section by the longitudinal elongation and shrinkage. The longitudinal forces between stands are also influenced by tension or compression caused by the rolls.

The relative length of the flow line, along which each portion of strip moves from one roll stand to the next, depends upon the working conditions, such as the number of rolls, roll profiles, roll positions, horizontal distance between stands, and geometry of the product's cross-section. Therefore, the flow line of the edge portion is not always longer than that of other portions. For example, when the flow line of the center portion is longer than that of the edge portion, the center portion tends to elongate and the edge portion tends to shrink in the longitudinal direction.

11.2.2 Transversal Elongation and Shear in Strip's Plane

Products with wide cross-sections are roll formed from wide metal coils. The edge portions and, to a lesser degree, intermediate portions of those products are pulled by rolls in the transversal direction and

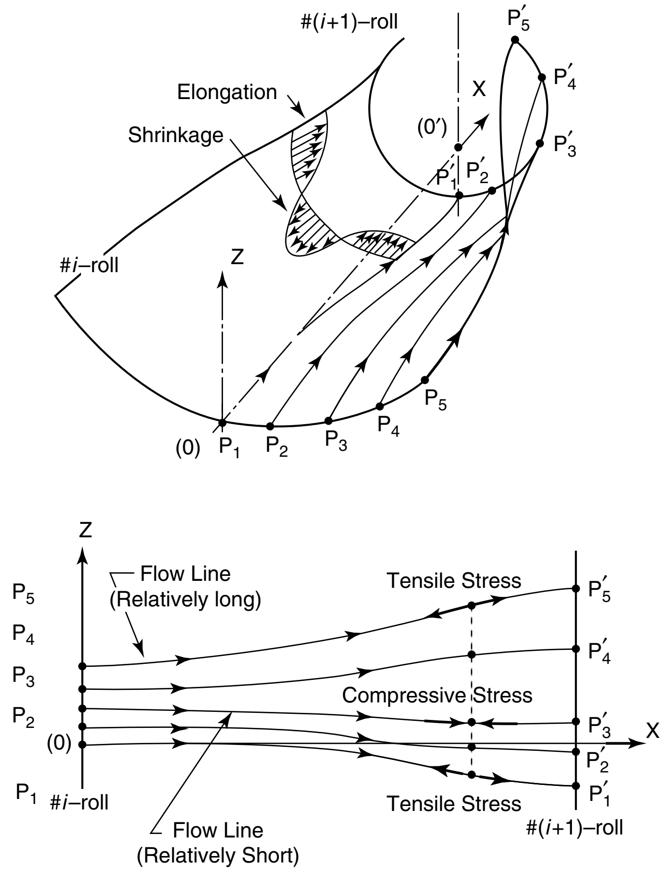


FIGURE 11.3 Mechanism of occurrence of longitudinal elongation and shrinkage of metal strip.

forced to shift toward the center of semiformed cross-sections, unless the products are formed only at their edge. This transversal shifting is usually induced by the transversal bending of the center portions of the coils (Figure 11.4).

When the coil is wide, the force required to pull the edge and intermediate portions toward the center of the semiformed cross-section becomes quite large, because a considerable amount of shear deformation in the coil's plane is required to shift the flat portions in the transversal direction.

Because of the large transversal tensile force necessary for this pulling, transversal elongation occurs in the metal. If the convex roll is pushed against the coil surface so strongly that it locally reduces the metal thickness, then considerable transversal elongation can occur at the bend lines. The transversal tensile force created by transversal bending has a strong effect on transversal elongation.

Furthermore, when the top of convex (male) rolls exerts excessive force on the inside surface of the bending corner, a sort of bulging deformation takes place (Figure 11.5). Both longitudinal and transversal elongation occurs in this case. Excessive transversal elongation, as shown in the following sections, can result in many kinds of defects.

As mentioned above, shear deformations occur at the edges and intermediate portions when they are pulled and forced to shift in the transversal direction. The shear deformation can significantly influence the shape of the corner portion (bend line) as well as the springback deformation of the cutoff end (flare). When it is excessive, it causes a sort of permanent buckling of the corner portion and distortion of cutoff ends.

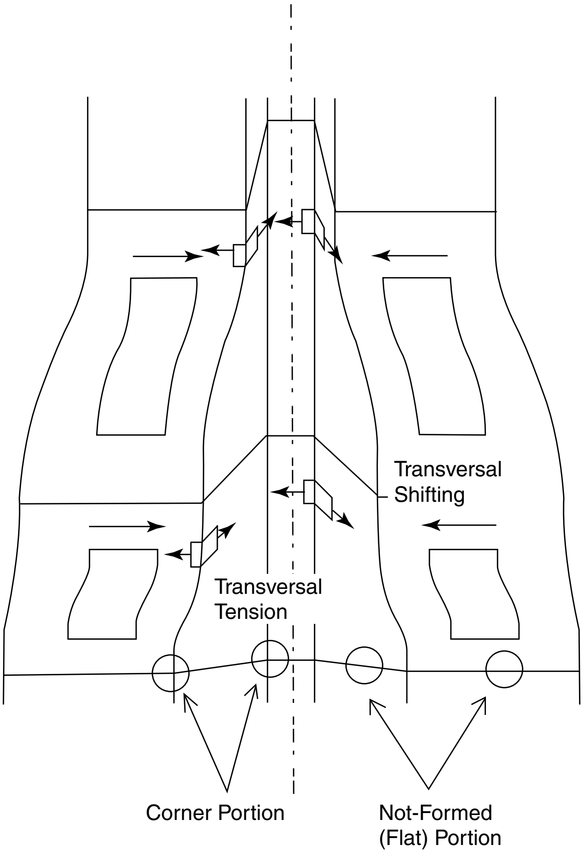


FIGURE 11.4 Mechanism of generation of transversal tensile force acting to metal strip.

11.2.3 Longitudinal Bending or Bending Back

When a metal strip enters into a roll gap, each portion of the strip moves along individual spatial flow lines, respectively inclining in the longitudinal direction. Some of those flow lines are close to the periphery of the convex roll and others are close to that of the concave roll (Figure 11.6). For example, at the breakdown forming passes for ERW (electric resistance welded) pipes, both edge portions of the strip usually enter the roll gaps along the flow lines close to the concave rolls, while the center portion of the strip flows into the roll gaps along the convex rolls.

Thus, each portion of the strip is bent in the longitudinal direction before entering into the roll gap and they are bent back to a longitudinal straight shape at the center or exit side of the roll gap. This repeated longitudinal bending and

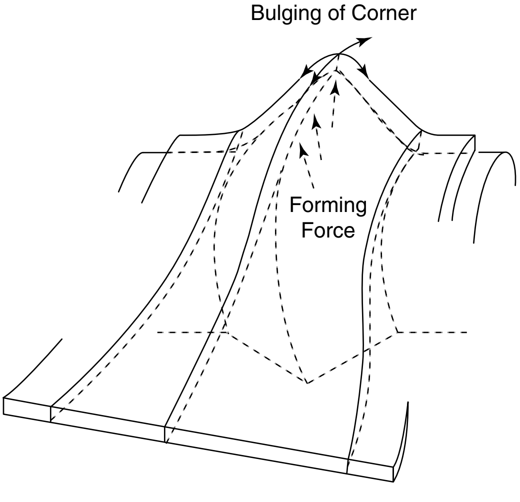


FIGURE 11.5 Bulging deformation of corner portion of product.

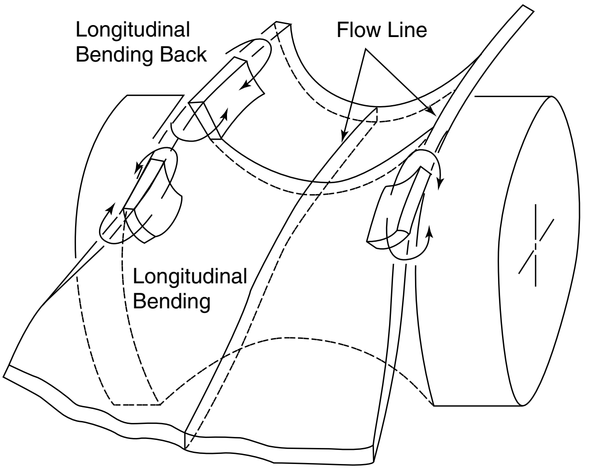


FIGURE 11.6 Mechanism of occurrence of longitudinal bending of metal strip.

bending back is especially extensive at the edge portion of the strip. The repeated longitudinal bending and bending back under the longitudinal tensile force (or tensile stress), which is usually high at the edge portion, contributes to the longitudinal elongation. The effect is similar to the progressive elongation of metal strips subjected to roller leveling.

11.3 Effects of Redundant Deformations on Product Defects

The redundant deformations significantly influence the transversal bending of the strip necessary to achieve the required cross-section of the product. They also affect stresses and strains induced in metal strips, springback deformations after forming, and the distribution of residual stresses in the products.

In other words, the redundant deformations cause a variety of defects in the products, such as longitudinal bow, camber or twist, edge wave, center (or pocket) wave, herringbone effect, thinning, cracking, splitting, flare (distortion of cutoff end), and dimensional inaccuracy (Figure 11.7).

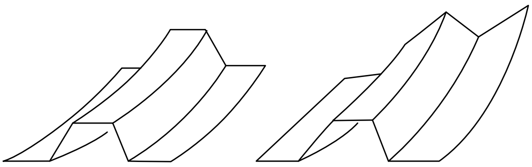
The mechanisms of the occurrence of these defects are summarized in the following sections.

11.3.1 Longitudinal Bow and Twist

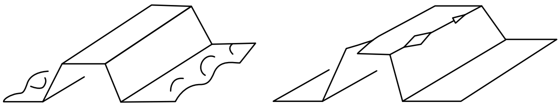
Longitudinal bow, camber, and twist are the most frequent defects in narrow roll formed products. As shown in Figure 11.8, these defects are caused by nonuniform transversal distribution of the longitudinal membrane strain, or in other words, the nonuniform longitudinal elongation and shrinkage of the strip. This nonuniformity is one of the fundamental characteristics of deformation of the strip during roll forming. The magnitude and direction of bow, camber, and twist follow the variation in the distribution pattern of the membrane strain (Figure 11.8).

The transversal nonuniformity of the longitudinal membrane strain is more or less inevitable. It cannot be avoided where flat metal strips are roll formed into products with cross-sections having heights (depths) and widths different from those of flat metal strips. Therefore, in roll formed products, the longitudinal elongation or shrinkage will not become uniform in the transversal direction. This is an inevitable phenomenon related to 3-D deformations of the strips during roll forming.

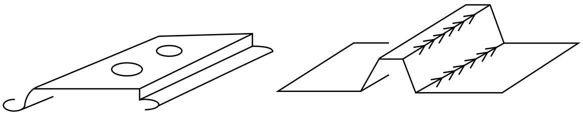
However, the magnitude of longitudinal membrane strain can be reduced and its unavoidable transversal nonuniform distribution can be rendered ineffectual by using proper conditions, in terms of number of rolls, roll profiles, roll positions, pass line, horizontal (between-stand) distance, and others. Therefore, the longitudinal bow camber and twist can be prevented or at least reduced by the following methods:



Warping (Bow)　Twisting

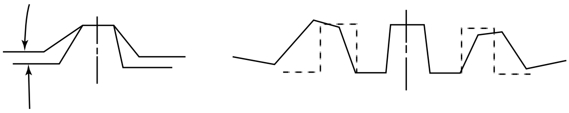


Edge Wave (Buckling)　Cracking



Center (Pocket) Wave　Corner Buckling (Herring Bone)

End Cross-Section



Intermediate Cross-Section (End Effect) Flare　Non-Uniform Spring Back

FIGURE 11.7 Schematic illustration of defects of products.

1. The appropriate number of passes should be used (Figure 11.9). When the number of passes is too small, the amount of transversal bending deformation caused by each pair of rolls tends to become excessive. In such cases, the strip is bent too much and too abruptly in the transversal direction, and some portions of it, such as the flange portion and edge portion are forced to rise steeply. Consequently, the difference between the spatial length of their flow lines and that of others becomes large. This causes enlargement of the nonuniformity of the longitudinal membrane strain distributing in the transversal direction.

If an adequate number of passes are used, then the strip is formed gradually and the longitudinal membrane strain can be reduced to an ineffective level. However, when too many passes are used, the cost of the forming mill, the tooling, and the setup time will be unnecessarily increased.

Various methods have been proposed to determine the appropriate the number of rolls. However, most of them have been based on experience, rough approximation, and assumptions.

In recent years, some mathematical models of roll forming were proposed and computer-aided simulation techniques were developed for investigating the deformation characteristics of metal strip in roll forming processes. By using such techniques, the overall behavior of the longitudinal membrane strain which occurs in the strip can be analyzed and evaluated much more exactly and consistently than before.

As the mathematical models and simulation techniques become more advanced, the effects of the number of rolls on deformation features of metal strips can be systematically analyzed, and the required number of rolls can be better determined.

2. In addition to the number of passes, the roll profiles and roll positions should be checked. If necessary, they have to be modified to reduce the longitudinal membrane strain (Figure 11.10). When the

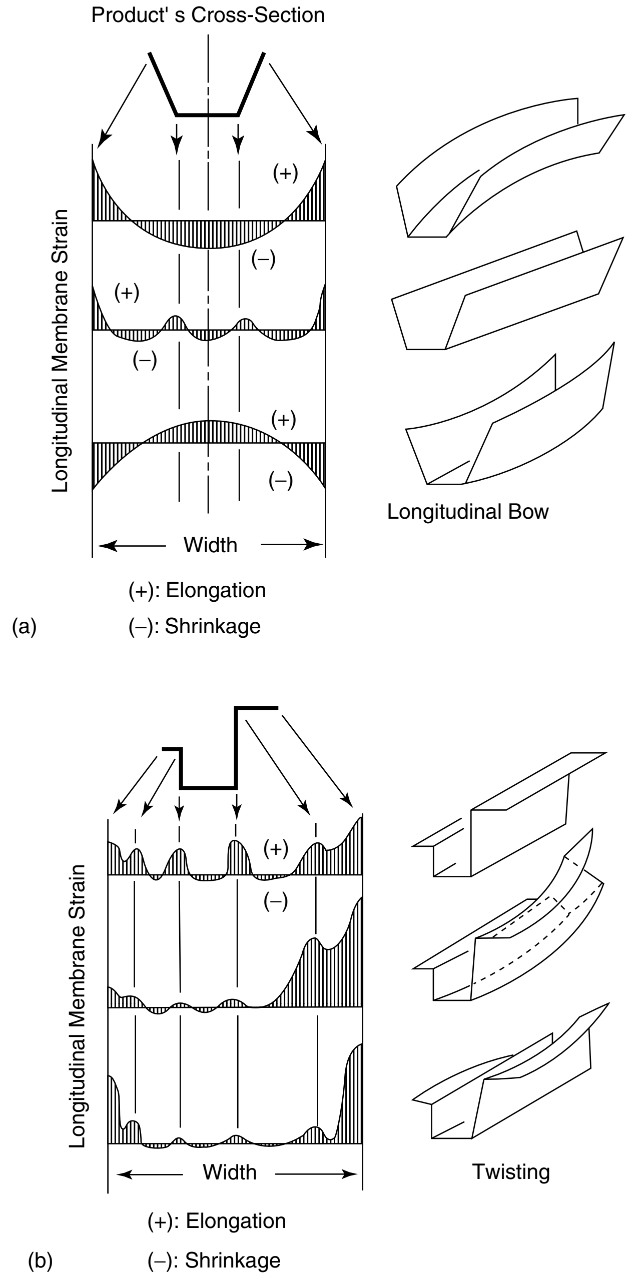


FIGURE 11.8 Relationship between transversal distribution of longitudinal membrane strain "ε_{xm}" and longitudinal warp or twist of product; (a) longitudinal bow; (b) longitudinal twist.

employed roll profiles and roll positions are not suitable for the smooth flow of each portion of the strip, the magnitude and nonuniformity of longitudinal membrane strain tend to increase. The influence of the roll profiles and roll positions on the behavior of the longitudinal membrane strain is very complicated. It is too difficult to clarify the relationships between them merely by trail and error. To establish those relationships, investigation based on the mathematical theory and application of the computerized simulation technique is indispensable. The effects of roll profiles and roll positions on the deformation

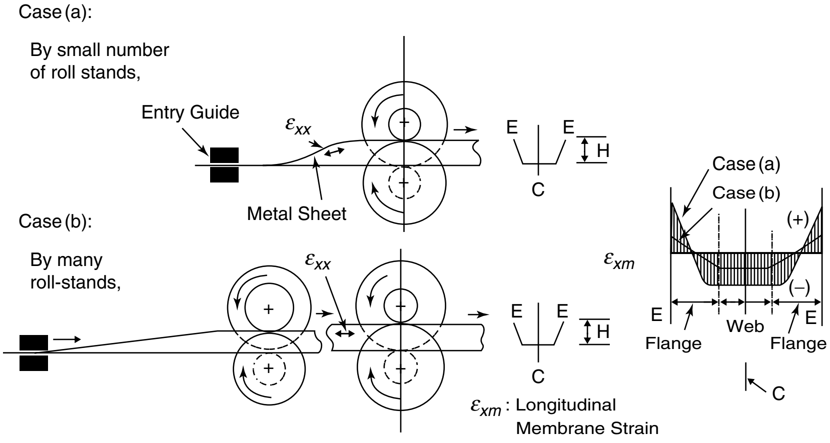


FIGURE 11.9 Effect of number of roll stands on the magnitude of "ε_{xm}."

features of metal strips, especially on the behavior of the longitudinal membrane strain, can be predicted consistently and systematically by utilizing the above techniques. As a result, suitable roll profiles and roll positions can be designed to reduce the longitudinal membrane strain.

3. Entry guides and intermediate guides can be utilized effectively to reduce the longitudinal membrane strain (Figure 11.11). Profiles and positions of such guides can be designed more easily than those of forming rolls. Setting up the guides and changing the flow lines is relatively simple. At the same time, they control the spatial lengths of the flow lines. As a result, the magnitude of longitudinal membrane strain is reduced and the undesirable effects of transversal nonuniformity can be minimized or eliminated.

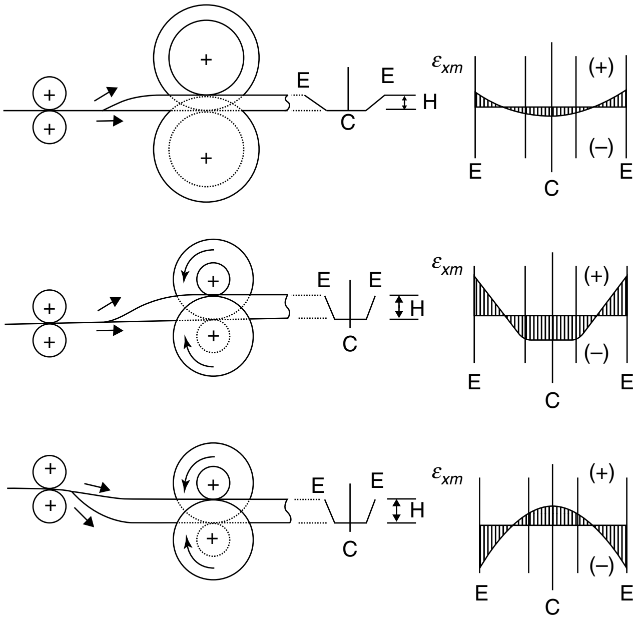


FIGURE 11.10 Effects of roll profile and roll position on transversal distribution of "ε_{xm}."

11.3.2 Edge Wave

The edge wave, caused by a sort of elastic or elastoplastic buckling, is a frequent defect. It takes place not only in finished products, but also in semiformed metal sheets moving from one pass to the next. It reduces product quality and, in some cases, makes it difficult to maintain a suitable roll forming operation.

In the manufacture of ERW pipes and tubes, the complete prevention of edge wave is important. Once edge wave takes place, for instance, at the breakdown pass or fin pass forming stage, complete and reliable welding of the edges becomes very difficult or impossible (Figure 11.12). Therefore, to obtain a good weld, edge wave should be prevented.

Edge waves are also frequently observed during roll forming of wide floor decks, sidings, and roof decks formed from thin metal (Figure 11.13).

The edge wave is caused by excessively large longitudinal membrane strain, which occurs locally at the edge portion of the coil. When, as a result of small thickness or the geometry of the cross-section, large edge elongation is unavoidable and the longitudinal stiffness of the edge portion of the partially or fully formed product is small, edge wave tends to occur.

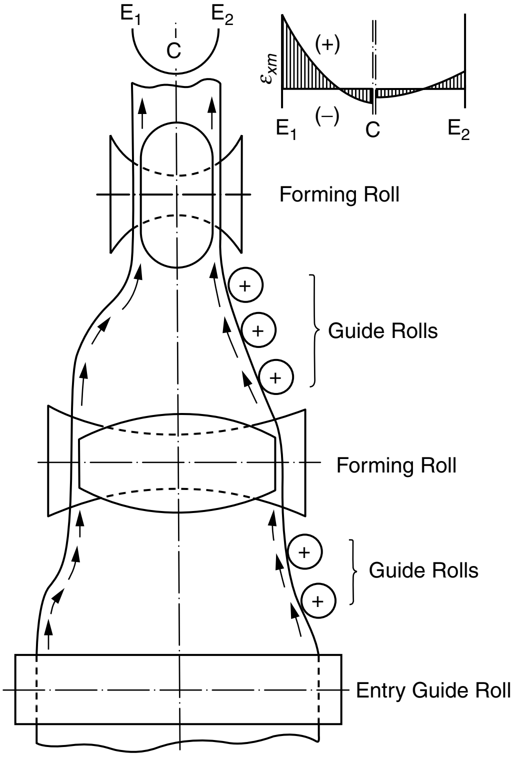


FIGURE 11.11 Modification of flow lines by guide rolls for reducing "ε_{xm}."

Edge wave is caused by elastic or elastoplastic buckling. The mechanism that creates the buckling is very simple. In general, at the initial stage of forming, the longitudinal elongation inevitably takes place at the edge portion of the strip, because the edge portion has to move both in the vertical and transversal directions. Additional elongation takes place when the edge portion enters the roll gap. However, the elongated edge portion must shrink again when it exits the roll gap, because the longitudinal length of each portion of the semiformed strip or product should be equal to keep the product straight. When the local edge elongation becomes excessive, it becomes very difficult or impossible for the elongated edge

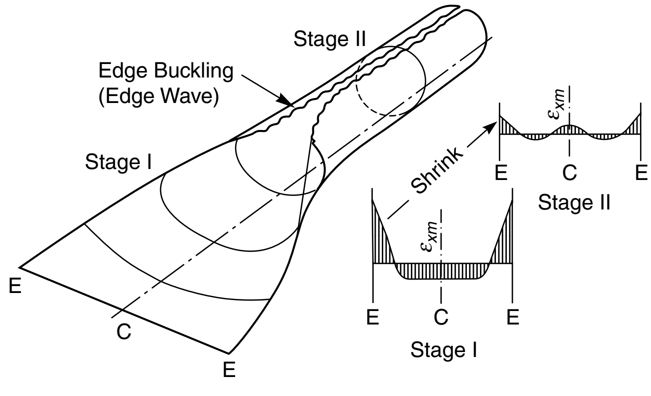


FIGURE 11.12 Schematic illustration of edge buckling (edge wave) taking place during roll forming of ERW pipes.

portion to shrink smoothly. In some cases, at the exit of the roll gap, the compressive stress acting upon the edge portion exceeds the critical value and, as a result, buckling (edge wave) occurs.

To prevent edge wave, the longitudinal elongation of the edge portion should be reduced below the critical value by using a sufficient number of rolls, roll profiles, roll positions, guides and a correct pass line. Effective simulation techniques are available to find the required number of rolls, their profiles and positions. One helpful technique will be explained later.

Some other countermeasures can be taken to prevent edge waves, as described below:

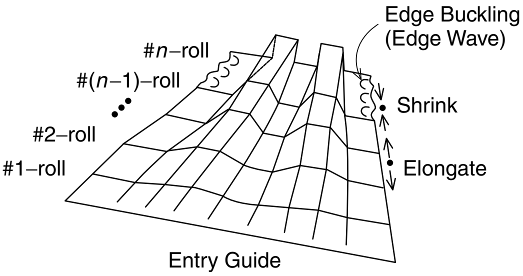


FIGURE 11.13 A typical edge wave which occurs in products made from coils with large width and small thickness.

1. The first edge wave reducing/preventing method is called the "local heating method" (Figure 11.14). The edge waves are caused by localized edge elongation, which is plastic deformation. Therefore, to prevent edge waves, the contribution of the plastic deformation should be reduced by utilizing the effect of thermal deformation induced by local heating of the strip.

For instance, if the edge portion is heated between roll stands, then the local thermal longitudinal elongation (expansion) can be sufficiently close to the plastic edge elongation caused by the longitudinal force. Owing to the thermal elongation, the plastic elongation of the edge portion becomes relatively small. Consequently, the magnitude of the plastic longitudinal shrinkage of the edge portion occurred at the exit of the roll gap is reduced. Therefore, with the drop of temperature, the shrinkage of the edge portion occurs smoothly and edge waves can be prevented.

2. The second one is called the "preforming method." Although the longitudinal edge elongation can be reduced by using suitable rolls, it is almost impossible to prevent nonuniform elongation and shrinkage completely.

In this method, metal coils are preformed by either a "roller preformer" or a special, frequently called, "shape-correcting" leveler (Figure 11.15). The roller preformer or leveler has several crowned rolls or roll

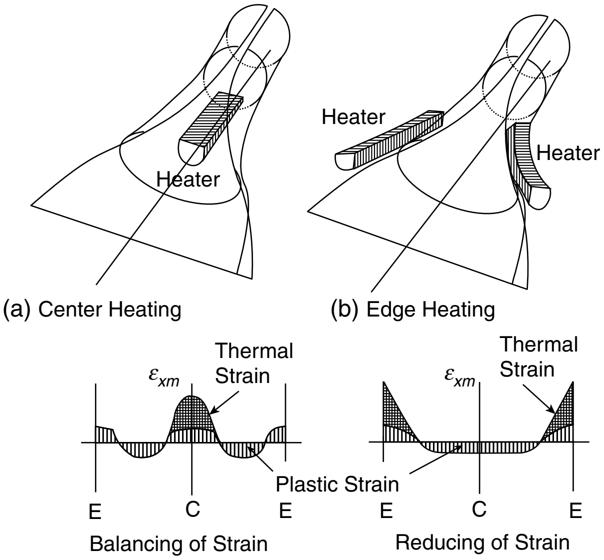


FIGURE 11.14 "Local heating method" for preventing edge wave.

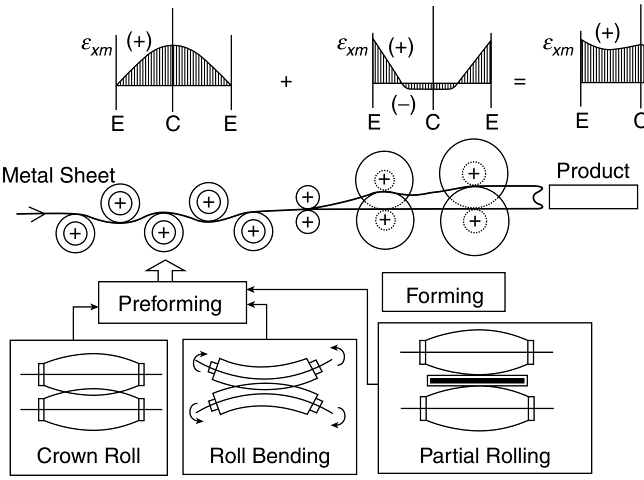


FIGURE 11.15 "Preforming method" for preventing edge wave.

bending systems. Coils passing through the preformer are repeatedly bent and bent back longitudinally by the crowned or bent rolls. The center and intermediate portions of the coils are subjected to longitudinal bending under the longitudinal tension because of utilization of crown rolls or transversally bent rolls arranged in a zigzag. Thus, the center and intermediate portions of metal sheets are longitudinally elongated, while the edge portion keeps its original length. After preforming, metal strips are formed by profile rolls into products, where the edge portions are longitudinally elongated much more than other portions.

The longitudinal elongation at the preforming stage is adjusted so that it compensates the nonuniform longitudinal elongation, which occurs at the forming stage. As a result, when the longitudinal elongation due to the forming is superposed upon the longitudinal elongation caused by the preforming, the elongation of sheet metal becomes almost uniform in the transversal direction. Thus the cause of the edge wave is eliminated and the occurrence of it is prevented.

3. The third method may be called the "smoothing flow line method." In this case, the flow line of the edge portion is made as smooth and short as possible by using guide rolls and shoes (Figure 11.16). During roll forming, the edge portion is repeatedly bent and bent back in the longitudinal direction under the longitudinal

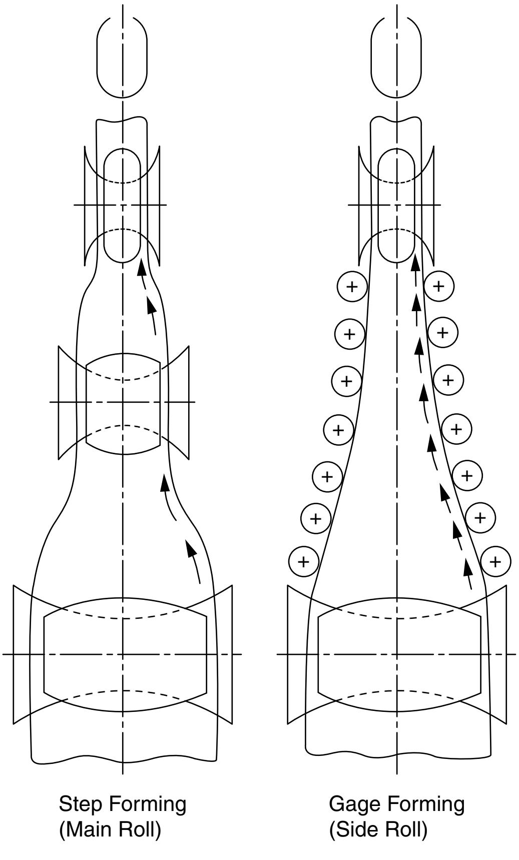


FIGURE 11.16 "Smoothing flow line method" for preventing edge wave.

tensile stress. Especially when it passes through roll gaps, this repetition of forward and backward bending becomes extensive and it contributes to the longitudinal elongation of the edge portion. It looks likes the longitudinal elongation of metal strip subjected to a tension roller leveler.

This longitudinal bending can be effectively reduced by adjusting the flow line to reduce the edge elongation, and thus preventing edge wave.

11.3.3 Center (Pocket) Wave

A pocket wave (usually called “center wave” or “oil canning”) is caused by slight elastic buckling, which occurs mainly at webs, flanges, and other nonbent portions of the cross-section. It is widely observed on products that have a wide cross-section with comparatively low thickness, such as roofing, siding, deck, panels, automotive components, garage, and other doors, as well as other wide products. Their webs and flanges usually have low stiffness against longitudinal buckling.

The mechanism of occurrence of pocket wave can be explained as follows.

1. When metal coils are roll formed, the edge and intermediate portions are pulled toward the center of the cross-section in the transversal direction. When they are pulled transversally, transversal tensile stresses are induced in the metal strip. The transversal tensile stress induced in the center portion is larger than those induced at the intermediate and edge portions. This is due to the fact that the transversal tensile stress induced at one portion corresponds to the transversal force necessary for pulling the strip at another portions. The portions of the strip, which become the bend lines (corners) of the products’ cross-sections, are bent transversally under the influence of such tensile stress. As a result, the bend lines, especially when they are located at the central zone of the strip, are significantly elongated in the transversal direction and, at the same time, following to transversal elongation, they shrink in the longitudinal direction (Figure 11.17).

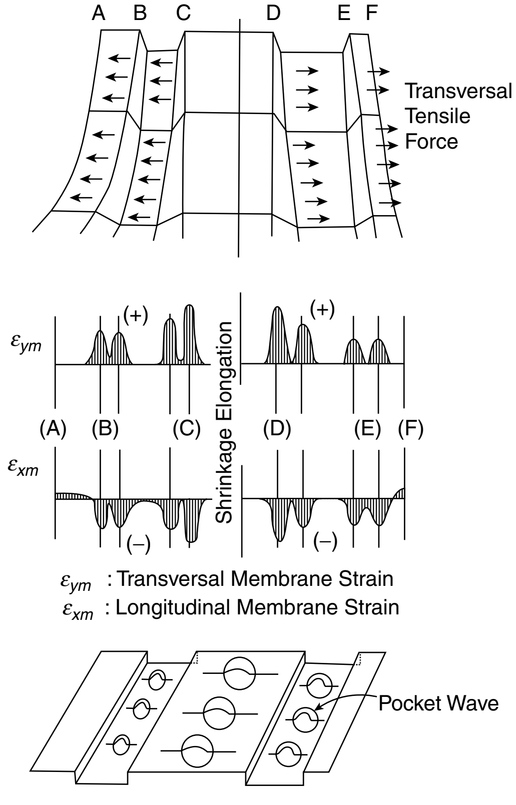

A
B
C
D
E
F
Transversal Tensile Force
ε_{ym}
(+)
(+)
Shrinkage Elongation
(A)
(B)
(C)
(D)
(E)
(F)
ε_{xm}
(−)
(−)
ε_{ym} : Transversal Membrane Strain
ε_{xm} : Longitudinal Membrane Strain
Pocket Wave

FIGURE 11.17 Mechanism of occurrence of center waviness (pocket wave) (shrink model).

When the bend lines (corner portions) shrink in the longitudinal direction, the longitudinal compressive stresses are induced in webs, flanges, and other flat (nonbent) portions. When the compressive stress is excessive relative to each portion’s stiffness, elastic buckling takes place there. This buckling appears as pocket (center) wave on the flat surface of the product.

2. Another mechanism contributes to the occurrence of pocket wave. When the corner portions are bent transversally by the convex and concave corners of the profile rolls, they elongate in the longitudinal direction as well as the transversal direction. In such cases, each corner portion deforms like a strip subjected to so-called “bulge forming.” However, when the semiformed strip comes out from the roll gap, the longitudinally elongated corner portions should shrink in the longitudinal direction to a length equal to the length of other portions, because all portions of the formed straight cross-section should have the same length. When the elongated bend line portions shrink, longitudinal compressive stress is induced in other nonbent portions

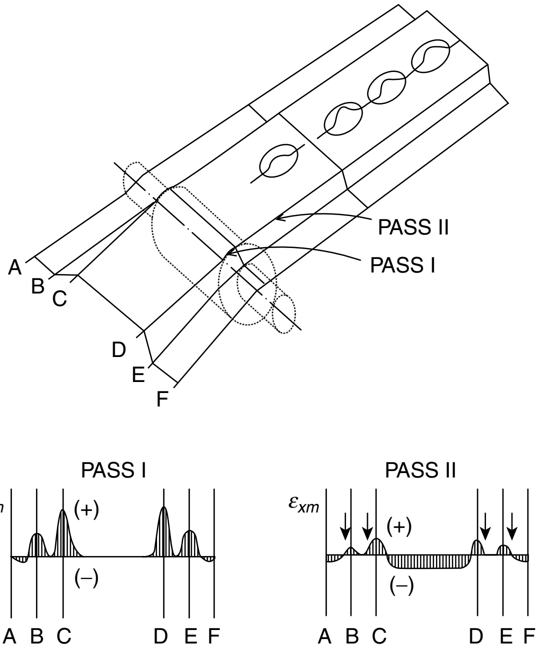


FIGURE 11.18 Mechanism of occurrence of center waviness (pocket wave) (elongate/shrink model).

(Figure 11.18). When compressive stress exceeds the critical value at the flat sections, longitudinal buckling (center waviness) occurs.

The following countermeasures can prevent or minimize center waviness.

1. Excessive transversal elongation induces excessive longitudinal shrinkage or elongation/shrinkage at the bend lines. Therefore, the transversal tensile stress affecting the bend lines and the transversal elongation induced there should be reduced. This reduction can be accomplished by reducing the transversal shifting of each portion of the strip by making the roll gap as large as possible. An unnecessarily small roll gap, through which the edge and intermediate portions of the coil have to shift in the transversal direction, may increase the localized transversal elongation of the bend lines.
2. At the same time, the sequence for bending corner portions should be optimized. In general, the corners of the center portion should be bent prior to those of the intermediate and edge portions. Moreover, the amount of bending (deformation) necessary for making up the required corners should be divided and allotted appropriately to sequential bending steps performed by profile rolls.
3. In some cases, use of guide rolls and shoes is effective for promoting transversal shifting of the edge and intermediate portions of the coil.
4. Moreover, decreasing the radii of the convex corners of the rolls should occur gradually, not suddenly. The bending radii should not be too small at any pass. Small radii tend to induce localized high transversal elongation at the bend lines. Small radii also obstruct smooth transversal shifting of the edge and intermediate portions.

11.3.4 Corner Buckling (Herringbone Effect)

Localized longitudinal elongation tends to occur frequently at corner portions when products have rather wide cross-section and the material is thin. When these elongated corner portions shrink in the longitudinal direction at the exits of roll gaps, in some cases, pocket waves take place at webs, flanges, and other flat (nonbent) portions. This happens when the stiffness of those portions is relatively low. When their stiffness is relatively high and that of the corner portions is comparatively low, corner buckling deformation takes place at the corners and adjacent areas (Figure 11.19). This is a sort of plastic shear buckling and small waves appear periodically along the corners. Generally, each wave inclines to the longitudinal direction, hence the term "herringbone" waviness. This inclination is caused by the shear buckling deformation.

To prevent corner buckling (herringbone effect), similar precautions must be taken as in the case of pocket waves. The most important objective is prevention of excessive longitudinal elongation at corner portions by supporting and enhancing the transversal shifting of the edge and intermediate portions of the coil.

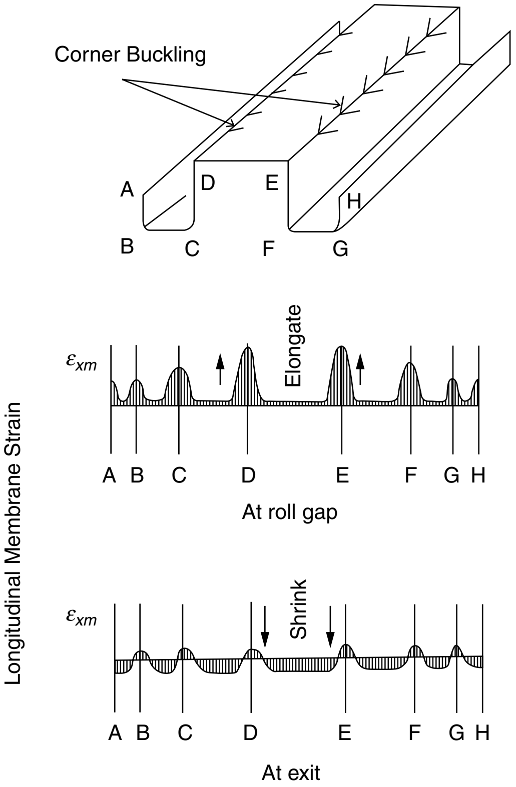


FIGURE 11.19 Mechanism of occurrence of herringbone effect (corner buckling).

11.3.5 Edge Cracking and Splitting

When the transversal tensile stress or elongation exceeds the critical value at the corner portions of the cross-section, cracking or splitting of metal takes place there. This kind of cracking or splitting is often observed in cases where the coil is wide, the material is thin, and the product has many sharp corners; this situation is aggravated if the metal has poor formability.

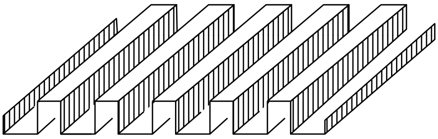
Again, the countermeasures necessary to prevent cracking and splitting are almost the same countermeasures for preventing pocket waves and corner buckling.

11.3.6 Nonuniform Springback Deformation of Panels

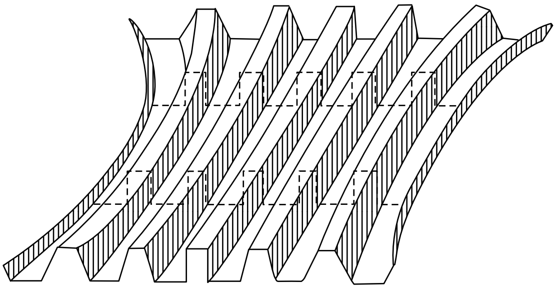
When strips are roll formed, they are subjected to various redundant deformations, as well as transversal bending. This means that the strips are bent transversally under the influences of the additive transversal and longitudinal tensile (or compressive) strains and stresses. Those influences are clearly observed when springback deformations of formed sheet metals take place.

The transversal and longitudinal membrane strains and stresses usually affect the transversal springback deformation of the strip significantly. The shape of the product changes in correspondence to the amount of membrane strains and stresses. In general, the membrane strains and stresses, irrespective of whether they are tensile or compressive, significantly reduce the amount of springback deformation, which takes place following transversal bending. For instance, if the transversal or longitudinal membrane strain is sufficiently large, then the springback deformation becomes zero.

When wide coils are formed into roof decks, sidings, and similar products, transversal tensile strain is induced at every corner of the cross-section. However, the transversal tensile strain induced at the corners located at the center portion of the panels is usually larger than that induced at the corners located at intermediate and edge portions. This means that the amount of springback deformation, which takes place at the corners at center portion, is smaller than that at the corners at intermediate and edge



Before Spring Back



After Spring Back

FIGURE 11.20 Schematic illustration of flare (nonuniform springback deformation).

portions. In other words, the amount of springback deformation at the edge portion is expected to be larger than those at other portions. Thus, nonuniform springback deformation takes place in the transversal direction (Figure 11.20).

Nonuniform springback deformation causes dimensional inaccuracy and, in some cases, cross (transversal) bow (Figure 11.21). Flare like this is inevitable; therefore, the roll profiles should be designed by taking such nonuniform springback deformation into consideration.

Similar problems and defects in products are observed when precut sheets are roll formed. In these cases, the front and tail ends of the strip are transversally bent without the influence of effects of restrictions imposed by neighboring rolls. They are formed (i.e., transversally bent) under the effects of longitudinal and transversal stress and strains smaller than those for the longitudinal midportion of the strip. At the front and tail ends (entry and exit ends) of the strip, the longitudinal stress is released, because those ends are not clamped (held) simultaneously by neighboring profile rolls. On the other hand, the midportion of the strip is formed under the restriction imposed by the simultaneous clamping of plural pairs of profile rolls arranged in tandem.

Therefore, in general, the amount of springback deformation at the entry and exit ends of cutoff metal sheet is larger than that of the midportion. This difference causes the longitudinal nonuniformity of height and width of the product's cross-section.

The longitudinal nonuniformity of the springback deformation may be reduced or eliminated by using a gap control system at several stands, installed at the final stage of forming

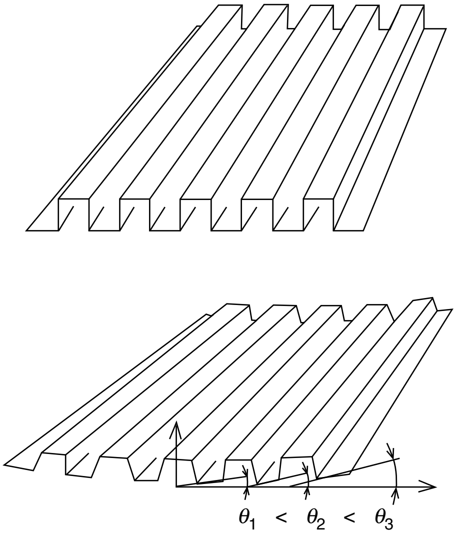


FIGURE 11.21 An example of flare causing cross-bow.

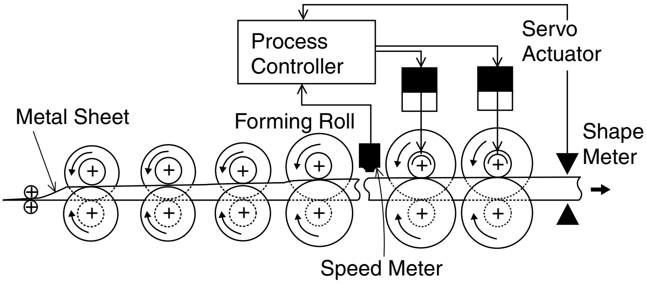


FIGURE 11.22 Conceptual illustration of a roll gap control system for preventing flare in sheet fed lines.

(Figure 11.22). At these stands, the roll gaps are adjusted to be small when the entry and exit ends of the sheets are formed, and are slightly opened when the midportions are formed. The small roll gap enhances the restriction imposed upon the top and bottom ends of metal sheet by the rolls and, consequently, the amount of springback deformation is reduced. Thus, the longitudinal nonuniformity of springback deformation is corrected and the geometrical inaccuracy of product is improved.

The sequence to adjust the roll gap should be studied and decided upon by taking into account the geometry of the product's cross-section, the mechanical properties of the strip, the number of available stands, and other forming conditions.

11.3.7 Flare After Cutting to Length

When roll formed products are cut off into pieces after forming, the entry and exit cross-sections of each piece are frequently flared due to springback deformation. In many cases, the distortion of both ends exceeds tolerance. The mechanism of occurrence of this springback distortion of cutoff ends can be explained as follows.

Springback distortion is mainly caused by the residual shear stress distribution in the thickness direction at the edge and intermediate portions of product's cross-section. As shown in Figure 11.23, the strip especially its edge portion, usually enters into the roll gap along the flow line, which is the lead-in part of the concave roll. The lead-in part of the rolls guide the semiformed strip into the roll

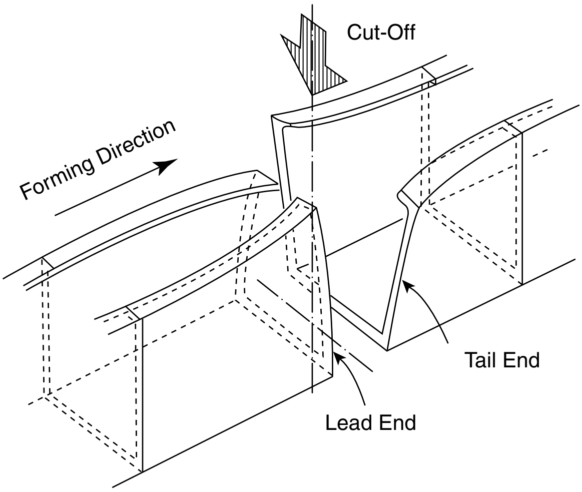


FIGURE 11.23 Flare of cutoff ends.

gap, as shown in the figure, although the section is wider than that of the roll gap. Owing to the flow line following the shape of the concave roll, shear deformation occur in the longitudinal section of the edge portion of the strip. This shear deformation takes place so that the outer layer of the strip, which is close to the surface of the concave roll, enters the roll gap faster than the inner layer, which faces the surface of the convex roll (Figure 11.24). However, at the exit end of the rolls, the inverse shear deformation occurs. As a result, all of the layers of metal sheet have to come out simultaneously and straight in the longitudinal direction. This shear deformation at the entry stage and inverse shear deformation at the exit stage generate residual shear stress in the metal sheet, especially at the edge portion.

When the formed product is cut off into pieces, the released residual shear stress distorts the entry and the exit ends of the formed products. In general, a springback deformation (flare) takes place, and, as a result, the shape of the product changes from the present state to the previous state. Therefore, both ends of the product tend to deform from the present state where the inverse shear deformation is finished to the previous state where they were subjected to the shear deformation at the inletting stage. That is, the state of deformation where the edge portion, and sometimes the intermediate portion, rounds to the concave roll.

Thus, springback distortion (flare) of the cutoff ends takes place. It should be noted that the distortion of the entry end and that of the exit end usually occur in opposite directions. For instance, as shown in Figure 11.24, the entry end tends to distort to close the cross-section and the exit end tends to open it. This interesting characteristic of the springback distortion of the cutoff ends is widely observed.

To prevent or minimize the flare springback distortion of the cutoff ends, the methods of (a) "over bending and bending back" and (b) "inverse bending by inner rolls" are used.

1. By the "over bending and bending back" method, the excessive transversal bending (overbending) is applied to the corners (bend lines) of the cross-section just before the final stage of forming. Afterward, those corners are bent back to the required shape or angle (Figure 11.25).

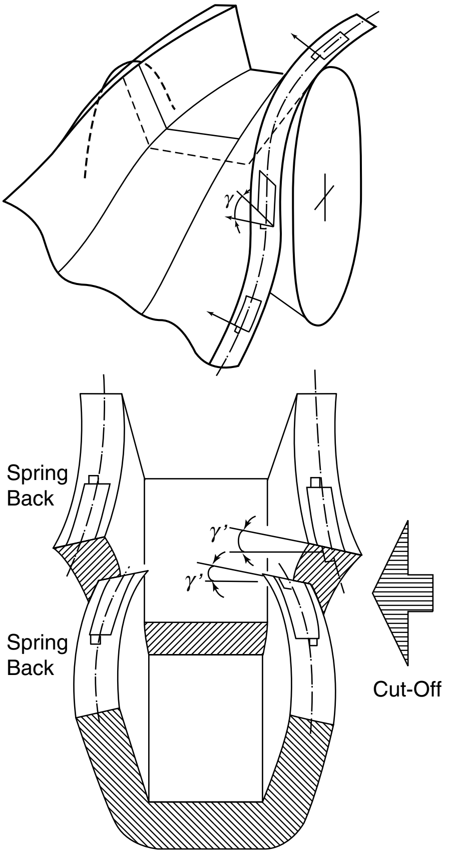


FIGURE 11.24 Schematic illustration of mechanism of occurrence of flare (distortion of cutoff ends) caused by reciprocal shear deformation in the longitudinal cross-section.

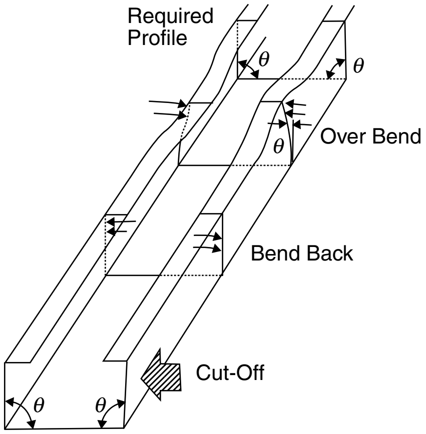


FIGURE 11.25 "Overbending and bending back" method to prevent flare.

The residual shear stress accumulated in the corner portions at preceding forming stages is canceled by the sufficiently large inverse shear deformation given at the bending back stage. Because of this "overbending and bending back," the springback distortion of the cutoff ends of the product can be reduced or prevented.

2. In the inverse bending method, as shown in Figure 11.26, the semiformed metal sheet is bent transversally to the inverse (opposite) direction by side rolls installed at the appropriate stage of forming process. The inverse bending rolls can be used effectively to give sufficiently large inverse shear deformation to the metal sheet. The inverse shear deformation, like the shear deformation given by the above mentioned bending back method, cancels the effects of the residual shear stress accumulated in the preceding forming stages, and eliminates the causes of springback distortion of the cutoff ends.

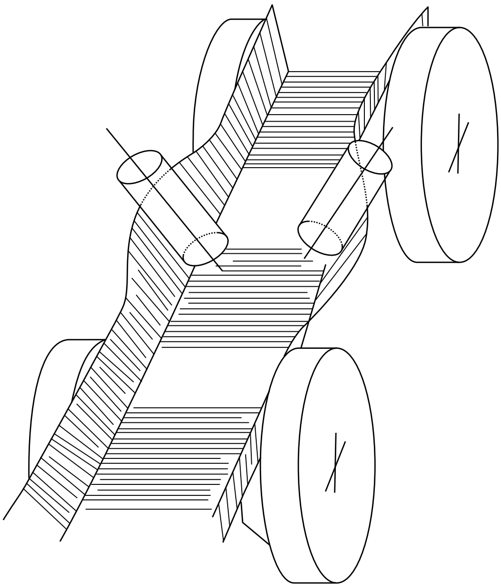


FIGURE 11.26 "Bending back by side (inner) roll" method to prevent flare.

11.4 Mathematical Simulation of the Deformation of a Metal Strip

In the roll forming process, metal strips are continuously and progressively formed into products with required transversal cross-sections and longitudinal shapes by a series of profile rolls arranged in tandem. In every process, each pair of profile rolls plays a particular role in forming the product's cross-section and shape.

Generally, the number of rolls and their contours are designed by taking account not only of the geometrical intricacy of product's cross-section, but also the dimensions and mechanical properties of the metal strip to be formed. Moreover, the design of the rolls depends on the available forming passes, adjustability of roll position, changeability of the pass line, controllability of the roll gap, convenience of the roll changing system, and other influencing factors.

Until now, very few investigations have been conducted on the methodology for a theoretical approach to the design of rolls, pass schedules, equipment, and processes. This is partly due to the fact that deformation of the strip during roll forming is one of the most difficult and complicated deformations for theoretical analysis. Therefore, for a long time, the approach to roll forming technology has been based on past experience and trial-and-error methods. As a result, the details and theory of deformations of the strip remain unclarified.

In order to remedy this situation, in recent years, the mathematical theory of roll forming has been actively investigated and has made remarkable progress. Computerized simulation techniques for analyzing details of deformation features of the strip in the roll forming processes are now being developed from various aspects. Furthermore, utilizing such simulation techniques, automated roll design systems are also being developed. These techniques and systems are going to be used to make diagnosis of rolls, equipment, processes and working conditions, determine the required modifications to them, and discover measures to improve product quality. The outline of the most advanced simulation technique and automated design system is explained in the following sections.

11.4.1 Mathematical Expression of Deformed Metal Strip

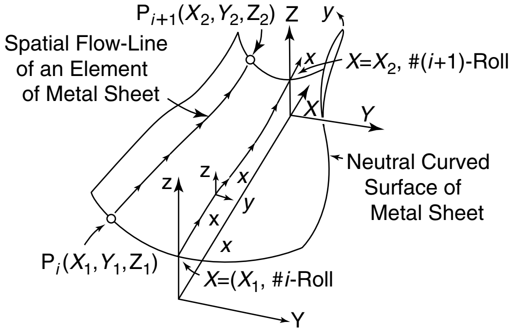


FIGURE 11.27 The coordinate systems for analysis and schematic illustration of the deformed curved surface (deformed neutral surface in thickness direction) of strips between # (*i*) and (*i* + *1*)-roll stands.

Figure 11.27 shows the coordinate systems used for the mathematical formulation and analysis as well as a typical deformed curved surface of the strip positioned between two roll stands. Here, the (X, Y, Z) coordinates represent the orthogonal coordinate system, which is fixed at an appropriate position in the concerning space. On the other hand, (x, y, z) coordinates express the curvilinear coordinate system located on the neutral curved surface of the deformed strip. The neutral curved surface means the curved surface, which is included in the middle of the thickness of the deformed strip. Hereafter, this neutral curved surface will be referred to as the "deformed curved surface of the strip."

The x-axis is defined as the horizontal axis and coincides with the forming (longitudinal) direction. In Figure 11.27, $X = X_1$ and $X = X_2$ represent the positions of # (i)-roll stand, and # ($i + 1$)-roll stand, respectively.

To express the 3-D deformed curved surface of the strip between two roll stands, a normalized function $S(X)$, named as "shape function" is introduced. For the present, $S(X)$ is tentatively defined by the next equation.

$$S(X) = \sin[(\pi/2)\cdot(X^*/L)^n]$$
$$X^* = X - X_1, \quad L = X_2 - X_1 \tag{11.1}$$

Here, L is the (horizontal) distance between the two roll stands. The shape function $S(X)$ represents the 3-D pattern of spatial flow lines along which each portion (or element) of the strip moves from # (i)-rolls to # ($i + 1$)-rolls. It changes from 0.0 to 1.0 as X changes from X_1 to X_2.

Figure 11.28 shows the calculated curves of $S(X)$. The value of $S(X)$ is a function of a parameter "n." As shown in this figure, the pattern of those curves is remarkably affected by the value of "n." When "n" is small, the value of $S(X)$ increases from 0.0 to 1.0 gradually as X changes from $X = X_1$ at the location of # (i)-rolls to $X = X_2$ at the # ($i + 1$)-rolls. However, when "n" is large, $S(X)$ increases very slowly at the initial stage, but approaches 1.0 very rapidly at the final stage, just before the # ($i + 1$)-rolls. When $S(X)$ is

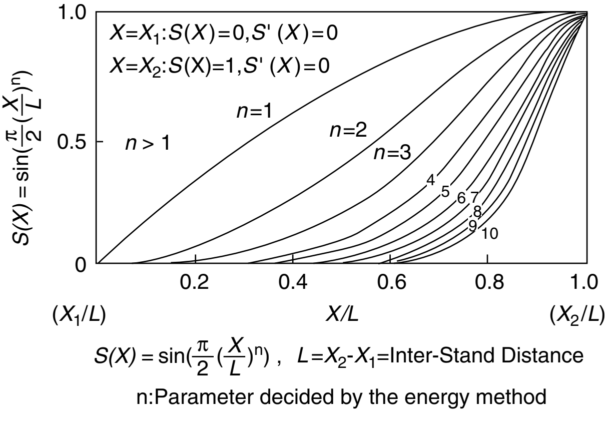


FIGURE 11.28 Calculated curves of shape function "$S(X)$" with different values of parameter in "n."

used for actual analysis, the value of "*n*" is determined through the mathematical procedure based on the so-called "energy method," where the value of "*n*" is theoretically searched so as to make the total power of deformation dissipated in the metal strip minimum.

Using the shape function $S(X)$, the deformed curved surface of the strip between # (i)-rolls at $X = X_1$ and # $(i+1)$-rolls at $X = X_2$ is expressed by the following equation:

$$\left.\begin{aligned} X &= X(x, y) \\ Y &= Y_1(y) + [Y_2(y) - Y_1(y)]\cdot S(X) \\ Z &= Z_1(y) + [Z_2(y) - Z_1(y)]\cdot S(X) \\ X &= X_1 \sim X_2 \end{aligned}\right\} \tag{11.2}$$

Here,

Y_1, Z_1:Y and Z coordinates of the profile of # (i)-rolls projected to the $Y{-}Z$ plane, which is perpendicular to x-axis at $X = X_1$

Y_2, Z_2:Y and Z coordinates of the profile of # $(i+1)$-rolls projected to the $Y{-}Z$ plane, which is perpendicular to x-axis at $X = X_2$.

From Equation 11.2, the following relations are derived

When $X = X_1$, $S(X) = 0.0$, then $Y = Y_1(y)$ and $Z = Z_1(y)$.
When $X = X_2$, $S(X) = 1.0$, then $Y = Y_2(y)$ and $Z = Z_2(y)$.

These relations show that Equation 11.2 is formulated on the following assumptions concerning the boundary conditions.

1. The cross-sectional profile of semiformed strip at each roll gap center (roll position, $X = X_1$ and/or $X = X_2$) coincides with the roll profile, respectively.
2. Every portion of the strip passes by the roll gap center ($X = X_1$ and/or $X = X_2$) along a horizontal flow line.

11.4.2 Incremental Treatment of Steady-State Deformation of Moving Metal Strip

Hereafter, the deformed curved surface of the strip between the adjacent two rolls stands is denoted as D.C.S. (deformed curved surface). The general mathematical expression of D.C.S. is described by Equation 11.2. However, Equation 11.2 expresses only the approximated 3-D shape of the semiformed strip without providing any details about the deformation features of it.

During roll forming, the metal strip is subjected to a so-called "steady-state deformation." That is to say, between every forming stand, each portion of metal strip is considered to move from # (i)-rolls to # $(i+1)$-rolls along D.C.S. On the D.C.S., every portion of the strip is bent, bent back, elongated or shrunk in various ways, under the complicated influence of working conditions. In order to calculate the stresses and strain occurring in the moving strip, the deformation of those portions should be analyzed incrementally by taking account of various mechanical constraints acting on them while they move (or flow) along D.C.S.

In order to perform an analysis like this, an incremental method is introduced, where the deformation of a strip having an original length of $\Delta\ell_o$ and width equal to the original strip width, is followed up and analyzed (Figure 11.29). The strip is considered to move from # (i)-rolls to # $(i+1)$-rolls and deform along D.C.S. Here, the following assumptions and mechanical restrictions acting on the sheet strip are introduced.

1. At every forming stage from # (i)-rolls to # $(i+1)$-rolls, the front (entry side) and rear (exit side) cross-sections of the deformed strip are respectively included in the planes which are perpendicular to x-axis.

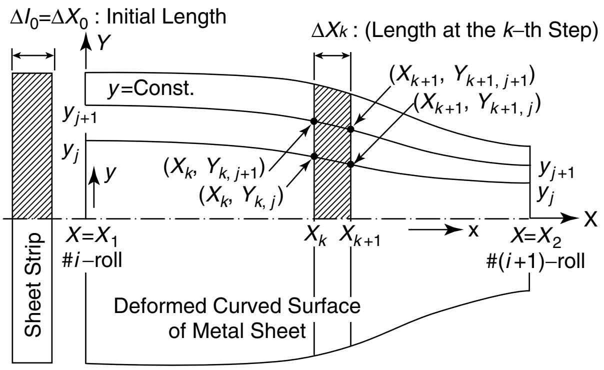


FIGURE 11.29 Geometry of strip which moves along the deformed curved surface from # (i)-rolls to # $(i+1)$-rolls under the equilibrium conditions for longitudinal and transversal forces.

2. The forces acting on the strip in the longitudinal (x) direction, which is equal to the sum total of longitudinal stress occurring in it, should be equal to the tension or compression acting on the strip between stands.
3. The forces acting on the strip in the transversal direction should satisfy the equilibrium condition.

The stress and strain components in the strip, which change as it moves along D.C.S. are analyzed by using the elastoplastic deformation theory. The calculative procedure will be explained in the next section. For the analysis and calculation, the strip is divided in the transversal direction into appropriate numbers of elements as shown in Figure 11.30.

11.4.3 Geometry of Deformed Strip and Element, and Definition of Strain Increments Occurring in Them

The deformation process of the strip is followed up and analyzed step-by-step as it moves from # (i)-rolls to # $(i+1)$-rolls. For this purpose, the process is divided into appropriate numbers of deformation steps.

In the following discussion, the concerned step being discussed is generally denoted as the (k)th deformation step or simply (k)th step. When the analysis of deformation of the strip has been finished from the first step to the $(k-1)$th step, the analysis of (k)th step is performed as follows.

At first, X coordinate of the entry (front) end of the strip, denoted by X_{k+1}, is established (Figure 11.29 and Figure 11.30). As mentioned already, the sheet strip is preliminarily divided into appropriate

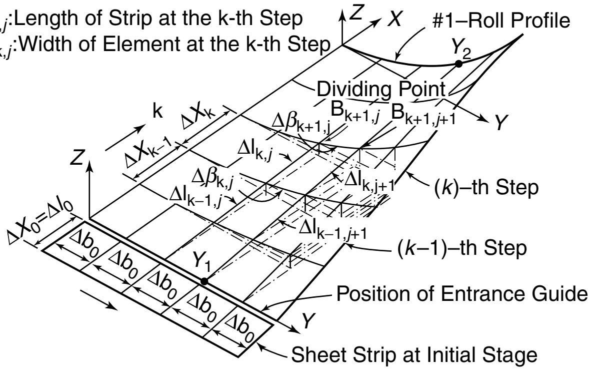


FIGURE 11.30 A continuous strip divided into narrow segments (strips) in the longitudinal direction and each strip is divided into sheet elements in the transversal direction. Strain increments occurring in each sheet element are calculated by the presented method and equations.

numbers of elements in the transversal direction. The coordinates of (j)th dividing point (nodal point) on its front cross-section at the (k)th step is denoted as $(X_{k+1}, j, Y_{k+1}, j, Z_{k+1}, j)$. Through the analysis of the $(k-1)$th step, the coordinates of the same dividing point at that step have been obtained and denoted as (X_k, j, Y_k, j, Z_k, j) are considered to be those of the (j)th dividing point on the rear cross-section of the sheet strip.

From these geometrical relations, the longitudinal membrane strain increment $(\mathrm{d}\varepsilon_{xm})$, occurring in the (j)th element of the sheet strip at the (k)th step, is calculated by Equation 11.3. Following similar considerations and using the geometrical relation between two transversally adjacent dividing points, the transversal membrane strain increment $(\mathrm{d}\varepsilon_{ym})$, occurring in the same element, is also calculated by Equation 11.4.

$$(\mathrm{d}\varepsilon_{xm})_{kj} = (\Delta\ell_{kj} - \Delta\ell_{k-1,j})/\Delta\ell_{k-1,j} \tag{11.3}$$

$$(\mathrm{d}\varepsilon_{ym})_{kj} = (\Delta b_{kj} - \Delta b_{k-1,j})/\Delta b_{k-1,j} \tag{11.4}$$

Here,

$$\Delta\ell_{k,j}- = (\Delta X_{k,j}^2 + \Delta Y_{k,j}^2 + \Delta Z_{k,j}^2)^{1/2}$$

$$\Delta b_{k,j} = \Delta b_{k-1,j}\cdot\{1.0 - \lambda\cdot(\mathrm{d}\varepsilon_{xm})_{k,j}\}$$

$$\Delta X_{k,j} = X_{k,j} - X_{k-1,j}$$

$$\Delta Y_{k,j} = Y_{k,j} - Y_{k-1,j}$$

$$\Delta Z_{k,j} = Z_{k,j} - Z_{K-1,j}$$

$\lambda = 0.0 \sim 1.0$: membrane strain ratio.

Thus, the membrane strain increments $(\mathrm{d}\varepsilon_{xm,}\mathrm{d}\varepsilon_{ym})$ in the x-direction (longitudinal direction), and in y-direction (transversal direction) occurring in the (j)th element of the strip at the (k) th step are defined. All of the geometrical relationships for these equations are shown in Figure 11.30. The membrane strain ration λ is determined so as to satisfy the equilibrium of the transversal force acting on the element concerned.

The bending strain increments $(\mathrm{d}\varepsilon_{xb}, \mathrm{d}\varepsilon_{yb})$ in the x-direction and y-direction occurring in the (j)th element of the sheet strip at the (k)th step are defined as follows by using a variable η. Here, η represents the distance between the respective layer of sheet element and its neutral curved surface. In this analysis, this neutral curved surface is considered to be the midlayer of sheet element, and the midlayer coincides with D.C.S. (Figure 11.31).

$$(\mathrm{d}\varepsilon_{xb})_{k,j} = \eta\cdot\{1/(\zeta_x)_{k,j} - 1/(\zeta_x)_{k-1,j}\} \qquad (\mathrm{d}\varepsilon_{yb})_{k,j} = \eta\cdot\{1/(\zeta_y)_{k,j} - 1/(\zeta_y)_{k-1,j}\} \tag{11.5}$$

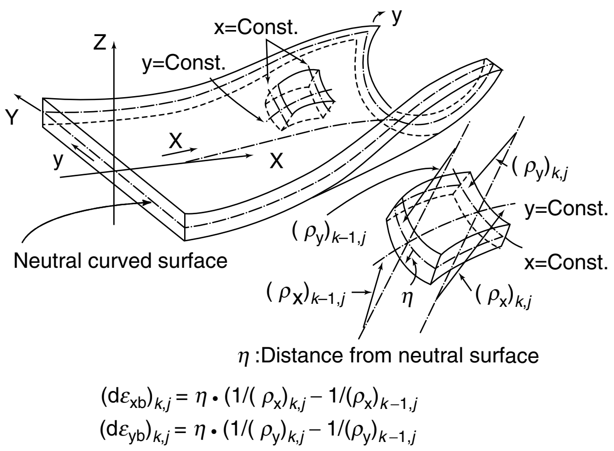

y
x=Const.
Z
y=Const.
Y
X
y
X
$(\rho_y)_{k,j}$
y=Const.
$(\rho_y)_{k-1,j}$
Neutral curved surface
x=Const.
$(\rho_x)_{k-1,j}$
η
$(\rho_x)_{k,j}$
η :Distance from neutral surface
$(\mathrm{d}\varepsilon_{xb})_{k,j} = \eta \bullet (1/(\rho_x)_{k,j} - 1/(\rho_x)_{k-1,j}$
$(\mathrm{d}\varepsilon_{yb})_{k,j} = \eta \bullet (1/(\rho_y)_{k,j} - 1/(\rho_y)_{k-1,j}$

FIGURE 11.31 Schematic illustration of bending deformation of sheet element.

Here, the curvatures of the element are defined in the x-direction and in the y-direction by the following equations, respectively.

$$1/\zeta_x = L/E, \quad 1/\zeta_y = N/G \tag{11.6}$$

E, G, L, and N are the “normalized parameters” of the curved surface, which are defined by the general theory of mathematics of geometry. If necessary, the curvatures ($\zeta_{x,}$ ζ_y) can be calculated approximately from the geometrical relationships between coordinates of the dividing points (nodal points) of the elements.

By summing the incremental membrane strains and the incremental bending strains, the total strain increments that occur in the (j)th element of the strip at the (k)th step are obtained. From the strain increments, the stress increments occurring in the respective element can be calculated by using the elastoplastic constitute equations. The details of the equations and the mathematical procedure are described in the next section.

11.4.4 Procedure to Optimize Deformed Curved Surface (D.C.S.)

By integrating the strain and stress increments from the 1st step to the (k)th step, the strains and stresses accumulated in each element of the strip at the (k)th step are obtained. This means that the distribution and transition behavior of stress and strain components occurring in the strip can be calculated while it moves from the first step to the (k)th step.

The longitudinal force F_x acting on the strip is calculated by summing the longitudinal stress component F_x distributed on the cross-section of the strip. If the value of F_x is not equal to the tension or compression between stands given by the working condition, then the assumed value of X_{k+1} is considered to be inappropriate. Therefore, with an aim towards getting a better approximation, the value of X_{k+1} is modified, following the mathematical theory for optimization. Then, the above-mentioned mathematical procedure for analyzing the deformation of the strip at the (k)th step is repeated. This amendment of the value of X_{k+1} is repeated until the value of F_x becomes equal to the given value.

When the analysis of deformation of the strip, which moves from # (i)-rolls to # $(i+1)$-rolls, has been finished, the total power of deformation $\dot{W}$, which is dissipated in the strip deformation stage between these two roll stands, is calculated. The total power of deformation $\dot{W}$ can be calculated by summing the power of deformation dissipated in the strip (or element) while it moves from # (i)-rolls to # $(i+1)$-rolls.

According to the theory of “energy method,” the total power of deformation $\dot{W}$ should have the minimum value. When this requirement is satisfied, the 3-D deformed shape of the strip and the distributing stress and strain components obtained by the above analysis are recognized as the best approximation for those of real deformation.

When the total power of deformation $\dot{W}$ is found to be other than the minimum, then the value of the parameter “n,” which is included in the shape function $S(x)$, is modified. Then the whole analysis of the deformation of the sheet strip, moving from # (i)-rolls to # $(i+1)$-rolls along the modified D.C.S. and defined by using the modified value of “n,” is repeated. Such modification of “n” and the whole procedure of analysis is repeated until $\dot{W}$ becomes minimum.

When the minimization of $\dot{W}$ is attained, the analysis is finished. This analysis is performed for every between-stand deformation where the results, with respect to one between-stand deformation, are used as the initial conditions for the next between-stand deformation. The block diagram of the procedure of analysis is shown in Figure 11.32.

11.4.5 Stress–Strain Relationships (Constitutive Equations)

The stress–strain relationships necessary for calculating stress increments are shown by Equation 11.7 ~ Equation 11.10, where the following assumptions and approximations are employed.

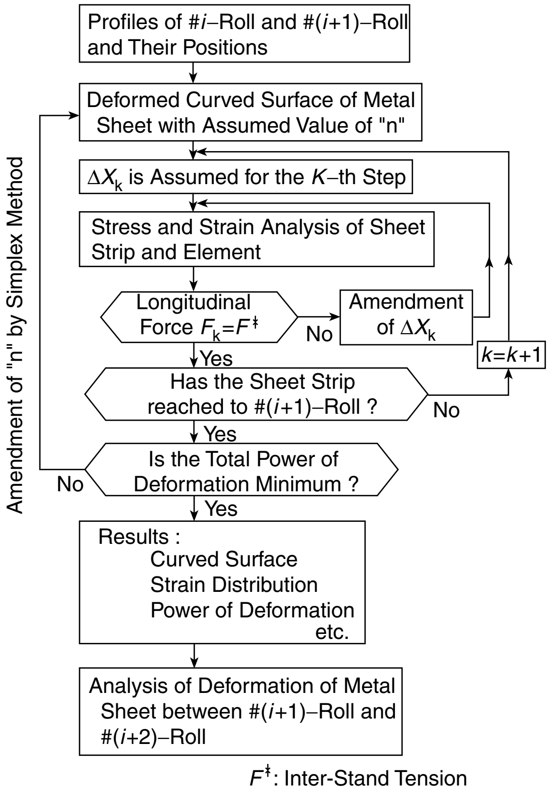

Profiles of #i–Roll and #(i+1)–Roll and Their Positions
Deformed Curved Surface of Metal Sheet with Assumed Value of "n"
ΔX_k is Assumed for the K–th Step
Stress and Strain Analysis of Sheet Strip and Element
Longitudinal Force F_k=F‡
No
Amendment of ΔX_k
Yes
Has the Sheet Strip reached to #(i+1)–Roll ?
No
k=k+1
Yes
Is the Total Power of Deformation Minimum ?
No
Yes
Amendment of "n" by Simplex Method
Results : Curved Surface Strain Distribution Power of Deformation etc.
Analysis of Deformation of Metal Sheet between #(i+1)–Roll and #(i+2)–Roll
F‡: Inter-Stand Tension

FIGURE 11.32 Block diagram of the procedure to analyze deformation of a sheet strip moving from # (i)-rolls # ($i+1$)-rolls.

(a) The x- and y-directions are considered to coincide with the principal axes of stress and strain in the strip.
(b) Stress component σ_z in the z (thickness)-direction is very small and can be neglected.
(c) The strain components in the x- and y-directions are the sum totals of membrane strains and bending strains in each direction.

Thus the following equations are introduced.

$$\mathrm{d}\varepsilon_x = \mathrm{d}\varepsilon_{xm} + \mathrm{d}\varepsilon_{xb}, \qquad \mathrm{d}\varepsilon_y = \mathrm{d}\varepsilon_{ym} + \mathrm{d}\varepsilon_{yb} \tag{11.7}$$

For elastic deformation, the stress–strain relationship is expressed by the following equations.

$$\mathrm{d}\sigma_x = \{(\mathrm{d}\varepsilon_x + \nu\cdot\mathrm{d}\varepsilon_y)\cdot E/(1-\nu^2)\} \qquad \mathrm{d}\sigma_y = \{(\nu\cdot\mathrm{d}\varepsilon_x + \mathrm{d}\varepsilon_y)\cdot E/(1-\nu^2)\} \tag{11.8}$$

For elastoplastic deformation, the next equation is used.

$$\begin{aligned} \mathrm{d}\sigma_{xx} &= \{(\sigma_y'^2 + 2P)\cdot\mathrm{d}\varepsilon_x + (-\sigma_x'\cdot\sigma_y' + 2\nu\cdot P)\cdot\mathrm{d}\varepsilon_y\}\cdot E/Q \\ \mathrm{d}\sigma_y &= \{(-\sigma_x'\cdot\sigma_y' + 2\nu\cdot P)\cdot\mathrm{d}\varepsilon_x + (\sigma_x'^2 + 2P)\cdot\mathrm{d}\varepsilon_y\}\cdot E/Q \end{aligned} \tag{11.9}$$

where

$$P = 2H\cdot\bar{\sigma}^2/9(E - H),\quad Q = R + 2(1 - \nu^2)\cdot P\ \ R = \sigma'^2_x + 2\nu\cdot\sigma'_x\cdot\sigma'_y + \sigma'_y 2,$$
$$\bar{\sigma} = (\sigma_x^2 - \sigma_x\cdot\sigma_y + \sigma_y^2)^{1/2}\ \ \sigma'_x = (2\sigma_{xx} - \sigma_y)/3,\quad \sigma'_y = (2\sigma_y - \sigma_{xx})/3 \tag{11.10}$$

E: Young's Modulus
ν: Poisson's ratio
H: Strain hardening rate

11.4.6 Power of Deformation

The total power of deformation $\dot{W}$, which is dissipated in the strip between # (i)-rolls and # ($i + 1$)-rolls, can be calculated by the next equation.

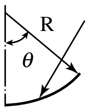
$$\dot{W} = \sum_k \sum_j \sum_m \Delta V_{k,j,m}\cdot\{(\mathrm{d}W^{\mathrm{p}})_{k,j,m} + (\mathrm{d}W^{\mathrm{e}})_{k,j,m}\} \tag{11.11}$$

Here, $\Delta V_{k,j,m}$ is the volume of one layer of strip element, which is obtained by dividing the strip element in the thickness direction. In order to perform the numerical analysis, the strip or its individual element is divided into appropriate numbers of layers in the z-(thickness) direction. The index "m" represents the (m)th layer. $\Delta V_{k,j,m}$ means the volume of one layer locating at the (j)th position in the y-direction and (m)th position in the z-direction at the (k)th step of deformation. $\mathrm{d}W^{\mathrm{p}}$ and $\mathrm{d}W^{\mathrm{e}}$ denote the power of plastic deformation and power of elastic deformation for unit volume. By summing the power of deformation dissipated in each layer, the power of deformation dissipated in one element is obtained. By summing the power of deformation in each element, the power of deformation dissipated in the strip at the (k)th step is calculated. Then the total power of deformation $\dot{W}$ can be obtained by summing the power of deformation dissipated in the sheet strip at every step from the first to the last step of the deformation between stands.

11.4.7 Some Results of Analysis

Some results obtained by the above-mentioned method will now be discussed with respect to roll forming processes manufacturing round steel tubes. As an example, for a 76.3 mm (3.0 in.) diameter tube made out of 4.5 mm (0.177 in.) thick mild material, the working conditions such as the required diameter, mechanical properties of metal, number of rolls, stands, pass-lines, and profiles of rolls are shown in Table 11.1.

TABLE 11.1 General Chart of Forming Conditions Employed for Case Study of Analysis

Dimensions		Tube t4.5×ϕ76.3		(Sheet t4.5×w280)			 Roll Profile		
Mechanical Properties of Metal Sheet		E = 21000 kgf/mm^2, ν = 0.3 , σ_e = 31.5 kgf/mm^2		H = 80 kgf/mm^2					
Forming Conditions		Number of Roll-Stands = 8,		Inter-Stand Distance = 800 mm ,		Speed = 40 m/min			(mm)
Stand No.		#1	#2	#3	#4	#5	#6	#7	#8
Profile Angle θ		30°	60°	90°	120°	150°	160°	170°	175°
Bending Radius R		229.18	114.59	76.39	57.30	45.84	42.97	40.44	39.29
Pass-Line	Bottom Line Const.	±0	±0	±0	±0	±0	±0	±0	±0
	Down-Hill	−10	−20	−30	−40	−40	−40	−40	−40
	Up-Hill	+10	+20	+30	+40	+40	+40	+40	+40

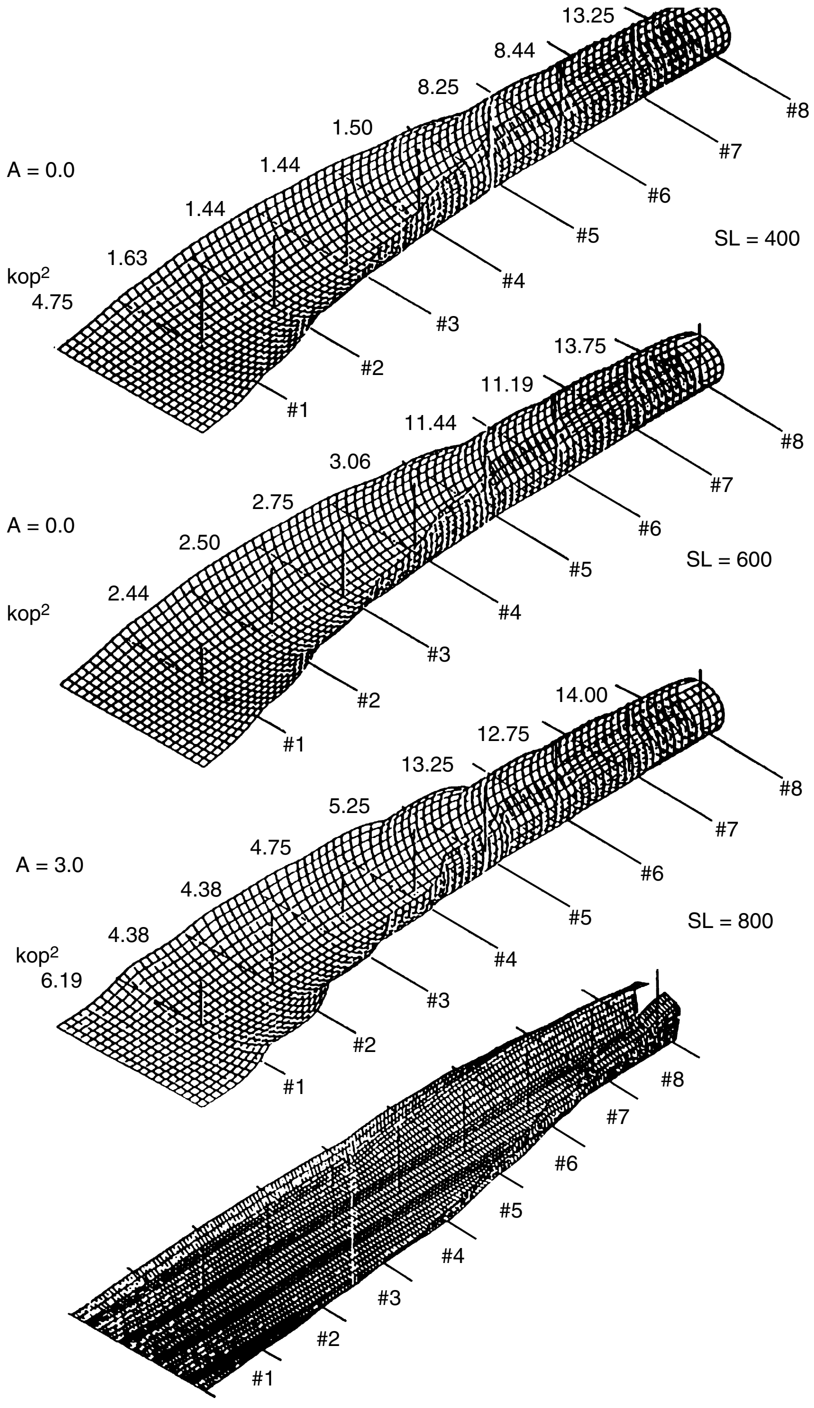


FIGURE 11.33 Some examples of 3-D curved surfaces of strips during roll forming of ERW pipes.

Figure 11.33 shows a deformed curved surface of the strip being roll formed by eight pairs of rolls under the given working conditions. The illustrated deformed curved surface is the optimized solution of the analysis for this case. Similar deformed curved surfaces for different working conditions can be easily obtained. From results like this, it becomes possible to know not only macroscopic characteristics

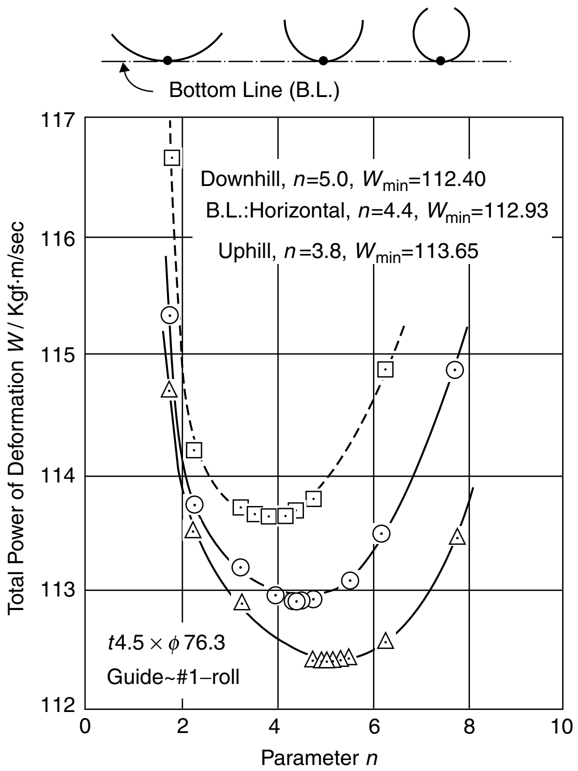


FIGURE 11.34 Relationship between parameter "n" included in "$S(X)$" and power of deformation "W" being dissipated in the strip (between the entry guide and # (1)-rolls) during roll forming of ERW pipes. The optimum value of "n" gives the minimum value of "W."

of deformation of the strip, but also detailed features of local deformation of each portion of it. For instance, the stress and strain distributing at arbitrary portions can be calculated.

Figure 11.34 shows the relationship between parameter "n" included in the shape function $S(x)$ and the total power of deformation $\dot{W}$. The diagram in the above the figure shows that the total power of deformation $\dot{W}$ has a minimum value related to the change of "n." This means that the above-mentioned mathematical model and calculation procedure, based on the energy method, can provide clear and reasonable results of simulation.

Figure 11.35 shows the calculated relationship between $\dot{W}$ and thickness of the strip (t). The relationship can be expressed as:

$$\dot{W} \propto t^{2.18} \tag{11.12}$$

This result coincides with the empirical knowledge that the power of deformation is

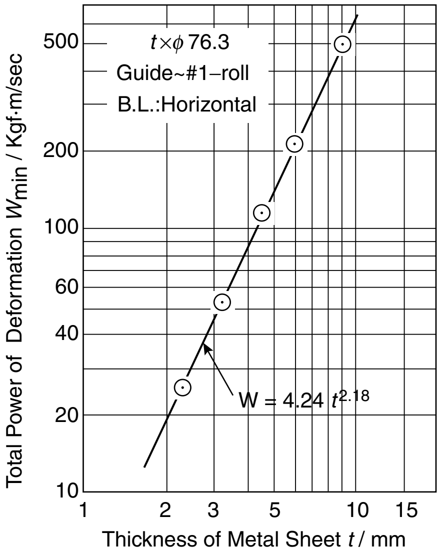


FIGURE 11.35 Relationship between strip thickness "t" and power of deformation "$\dot{W}$" dissipated during forming from entry guide to # (1) rolls, during roll forming of ERW pipes.

proportional to ($t^{2.0}$) in various sheet forming processes for which the bending deformation is dominant compared with other additive deformations.

Figure 11.36 shows the relationship between optimum value of "n" denoted by "n_{op}" and sheet thickness "t." It clearly shows that "n_{op}" increases gradually as "t" increases. This means that, when "t" is large, the strip moving from # (i)-rolls to # ($i+1$)-rolls, deform abruptly just in front of the # ($i+1$)-rolls. This tendency can be observed in actual production lines.

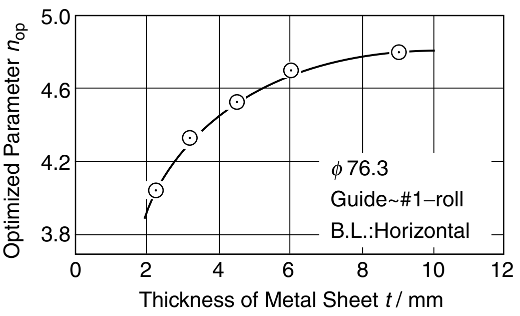


FIGURE 11.36 Relationship between sheet thickness "t" and optimized value of "n" for roll forming of ERW pipes.

Figure 11.37 shows some examples of the dynamic features of strains. This figure shows the transition of the longitudinal membrane strain ε_{xm}, occurring at the center, edge and intermediate position of the strip. The transition of ε_{xm} is consistently calculated through the whole forming process from the first roll stand to the eight roll stand.

The results indicate that large tensile strain occurs, and shows a peak value repeatedly at the edge portion of the strip during strip deformation between every forming stands. However, at the roll gaps, the transversal distribution of ε_{xm} becomes nearly uniform and the value of ε_{xm} becomes very small. If it becomes excessive, this edge elongation causes edge buckling (waviness) and other product defects. Therefore, in order to design the rolls and pass-schedules for manufacturing good products, it is important to know the overall behavior and characteristics of ε_{xm} as shown in this figure.

Thus, using the developed simulation method, it becomes possible to predict the distribution and transition features of each strain component in the strip. Possible problems may be predicted preliminarily, without actual trials. Therefore, it can be beneficial to predict potential problems without using actual rolls and to modify the rolls before they are made.

11.5 Computerized Design System for Roll Profiles

Utilizing mathematical theory and simulation techniques, computerized roll design systems are now being developed. Such design systems are expected to be useful to develop optimal flower diagrams, roll profiles and roll positions.

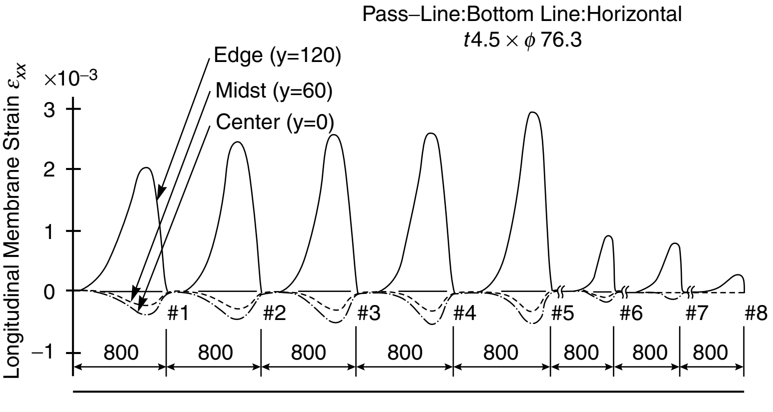


FIGURE 11.37 Some calculated results on behavior of longitudinal membrane strain "ε_{xm}" during roll forming of ERW pipes.

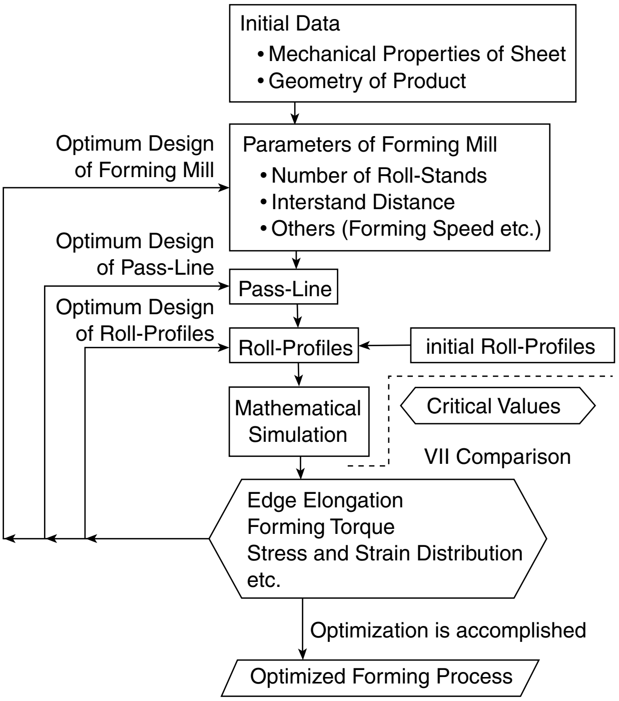

Initial Data
• Mechanical Properties of Sheet
• Geometry of Product
Optimum Design of Forming Mill
Parameters of Forming Mill
• Number of Roll-Stands
• Interstand Distance
• Others (Forming Speed etc.)
Optimum Design of Pass-Line
Pass-Line
Optimum Design of Roll-Profiles
Roll-Profiles
initial Roll-Profiles
Mathematical Simulation
Critical Values
VII Comparison
Edge Elongation
Forming Torque
Stress and Strain Distribution
etc.
Optimization is accomplished
Optimized Forming Process

FIGURE 11.38 Conceptual illustration of computer-aided engineering and design system for roll forming. (For design of rolls, roll positions, forming schedules, equipment, and processes.)

Figure 11.38 shows the flow chart of one of these advanced computerized design systems. This system is able to design a series of rolls to satisfy many requirements, including keeping the magnitude of edge stretch (edge elongation) below a critical value. It can also provide a series of roll profiles for a minimum number of passes without inducing any problems. Computerized design systems like this are now being used for various roll design projects for tubes and light gage section.

The results of application are show in the following sections, where two different criteria for the optimization of roll profiles were introduced.

1. The first criterion is for the minimization of edge stretch. The minimization of edge stretch is attained by making the maximum values of membrane strain $(\varepsilon_{xo})^{\#i}_{\text{MAX}}$, that occurs at the edge portion during every interstand forming process, equal to each other.
2. The second one is for the equalization of driving torque necessary for rolls, where the powers of deformation $(\dot{W})^{\#i}$ dissipated in metal sheet at each interstand deformation state are made equal to each other.

11.5.1 Flower Diagrams for Minimizing Edge Stretch

Two series of roll profiles designed for manufacturing round tubes with small $t{:}D$ ($t = 2.3 \times \phi 101.6$ mm or 0.090 in. thick × 4.0 in. diameter) and large $t : D$ ($t = 4.5$ mm $\times\ \phi\,48.6$ mm or 0.177 in. thick × 1.91 in. diameter) are shown in Figure 11.39. These rolls minimize edge stretch. The optimized allocation of the increment of profile angle $\Delta\theta^{\#i}$ to each roll and the optimized roll flowers for two cases are shown in the figure. It should be noticed that two kinds of roll flowers are shown with the same normalized dimension. The difference between two sets of roll flowers for small $t : D$ and large $t : D$ is clearly observed. The predicted values of $(\varepsilon_{xo})^{\#i}_{\text{MAX}}, = (\varepsilon_{xm})^{\#i}_{\text{MAX}}, (i = 1, 2, \ldots)$ are also shown in Figure 11.39 and it can be known that the equalization of $(\varepsilon_{xo})^{\#i}_{\text{MAX}}, (i = 1, 2, \ldots)$ is almost completely attained for each case.

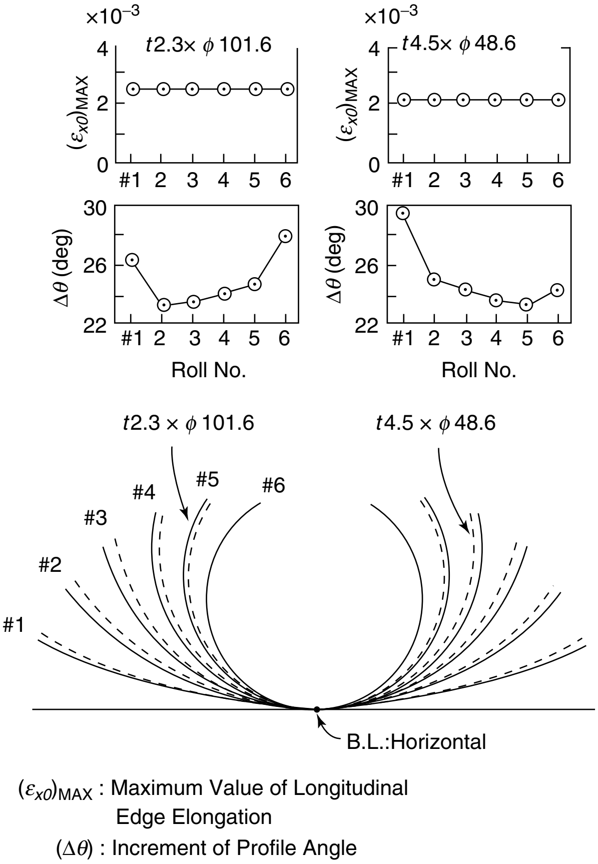


FIGURE 11.39 Some examples of designed roll profiles (so-called "roll flowers") for manufacturing ERW pipes. They are optimized so that the longitudinal membrane strain "ε_{xm}" is reduced to be minimal.

Figure 11.40(a)–(c) shows the optimized increment of profile angle $\Delta\theta^{\#i}$ allocated to each roll and the optimized roll flowers for the cases when various pass lines are employed. The dimensions of the round tube are $t = 4.5 \times \phi 101.6$ mm (0.177 in. thick × 4.0 in. dia). The descent of pass line height, denoted by DH, is changed in the range from 0.0 to 0.5 XH, where H denotes the depth of the semiformed cross-section of the strip at each roll stand. In each case, #5 rolls and #6 rolls are fixed on the horizontal line, where the bottom points of the semiformed cross-section at #5 stand and #6 stand are on a horizontal line. From these figures, it can be seen that there are suitable roll flowers for different pass lines in order to minimize the edge stretch.

11.5.2 Roll Flowers for Equalized Power of Deformation

Figure 11.41 shows the optimized allocation of the increment of profile angle $\Delta\theta^{\#i}$ and the optimized roll flowers for two cases when the values of $t : D$ are small ($t = 2.3 \times \phi 101.6$ mm or 0.090 in. thick × 4.0 in. diameter) and large ($t = 4.5 \times \phi 48.6$ mm or 0.177 in. thick × 1.91 in. diameter). The figure also shows the power of deformation $\dot{W}^{\#i}$ $(i = 1, 2, \ldots)$ has been attained almost completely. The optimized roll flower for small $t : D$ shown by bold lines and that for large $t : D$ shown by broken lines are clearly different from each other.

The effects of diameter D and wall thickness t of tubes on the power of deformation $\dot{W}$ are summarized as follows. When the wall thickness t is fixed, $\dot{W}$ decreases as the diameter D increases. This is due to the

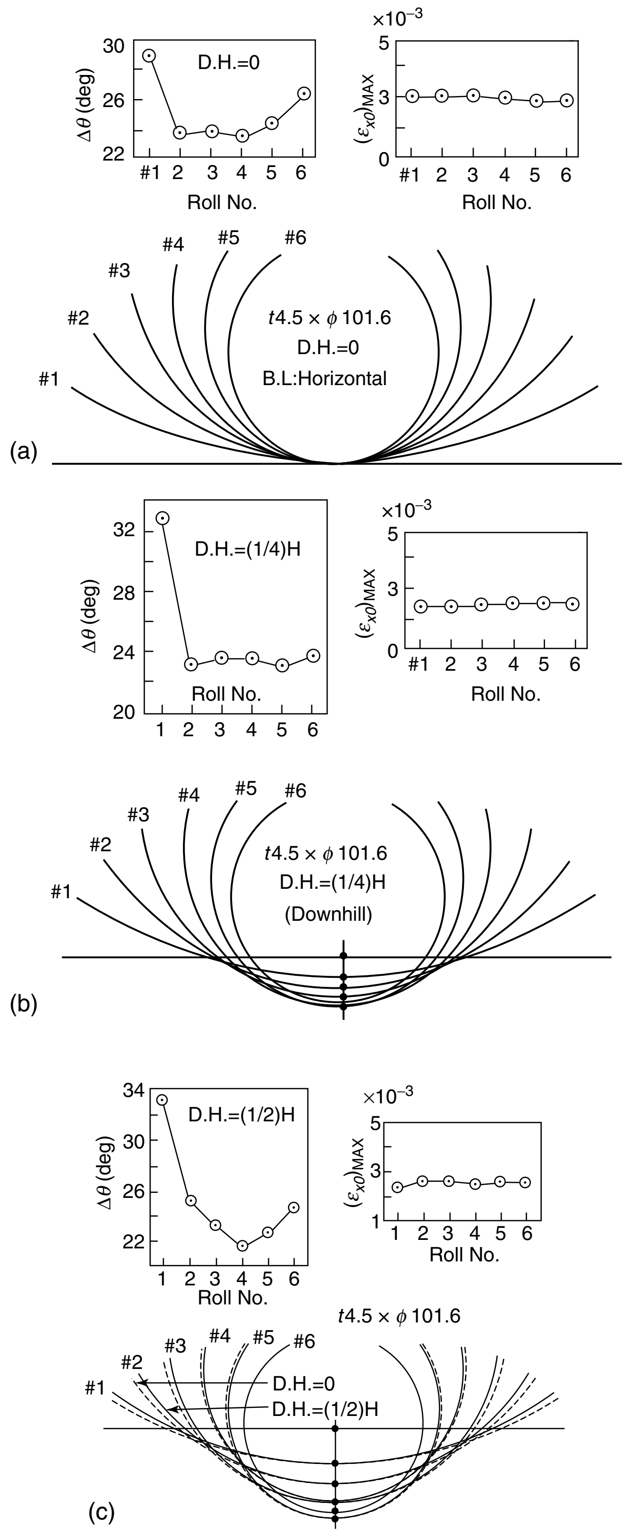


FIGURE 11.40 Optimized roll profiles corresponding to different descending pass lines for manufacturing ERW pipes.

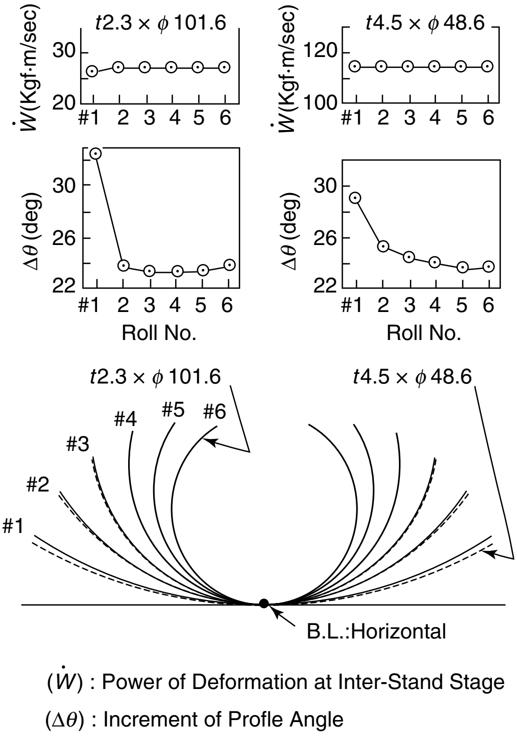


FIGURE 11.41 Designed roll profiles (roll flowers for ERW pipes). They are optimized so that the power of deformation "$\dot{W}$" dissipated at every interstand stage becomes equal to each other.

following fact: as D becomes small, the transversal bending deformation incurred by the metal sheet becomes large and the transversal bending strain occurring in it increases. At the same time, the strain hardening of the metal sheet becomes more and more critical. These effects increase the $\dot{W}$. On the other hand, as D becomes small, the volume of the metal strip decrease, which decreases $\dot{W}$. In the

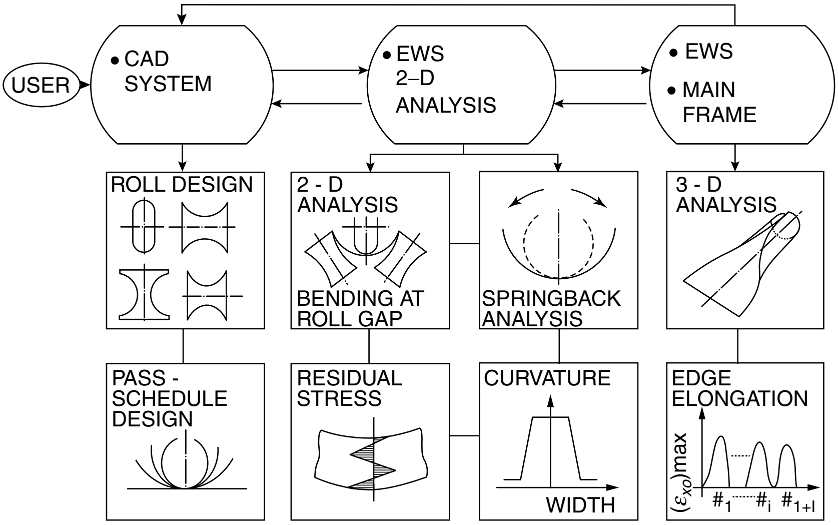


FIGURE 11.42 Framework of CAE system for roll forming.

usual cases, the effects of the increased strain and strain hardening are larger than those of the decreased volume.

As mentioned already, when the diameter of tube D is fixed, the power of deformation $\dot{W}$ given to the strip by each profile roll increases proportionally to (2.1 ~ 2.2)th power of wall thickness as follows:

$$\dot{W} \propto t^{2.1 \sim 2.2} \tag{11.13}$$

11.6 CAE for Roll Forming

Developed design systems can be used to design roll positions as well as optimal roll profiles. They also can be used for the design of equipment, and the diagnosis and correction of conventional rolls. Figure 11.42 shows the basic concept of one of those developed CAE systems.

12

Acquiring Roll Forming Lines, Education, and Training

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12.2 Different Paths to Start Roll Forming **12**-2
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George T. Halmos
Delta Engineering Inc.

12.1 Why Roll Form Products?

The most frequent reasons to consider roll forming are:

- Reducing manufacturing cost of a product or group of product
- Increase in sales volume of an existing product requires additional manufacturing capacity
- Introducing a new product

12.1.1 Reducing Manufacturing Cost

Products manufactured with roll forming lines usually cost less than those made by other methods. Incorporating other operations in the line, such as punching, notching, embossing, welding, adhesive bonding, painting, packaging, and others can further reduce the total manufacturing cost. The elimination of the material handling and inventory between different operations are additional contributors to the production cost reduction.

12.1.2 Additional Manufacturing Capacity Required because of Increased Sales Volume of an Existing Product

When the volume of brake formed, press formed, welded, extruded, or purchased components reaches a critical level; usually, roll forming is the most economical method to manufacture the increased product volume. The purchase of a roll forming line can frequently be justified with the reduction of labor and material cost, together with the elimination of the need for investment for additional press brakes, punches, press, or similar equipment.

12.1.3 Introducing New Products

For some new products, the only practical manufacturing technology is roll forming. For other products, alternative methods such as press brake or punch press forming or extrusion are available, but the product volume is high enough to justify roll forming. Roll forming can also be the only practical way to fabricate products from high tensile or special materials, producing variable lengths and hole patterns or manufacturing the product to very tight tolerances.

12.2 Different Paths to Start Roll Forming

When a decision is reached that a product should be roll formed, then the manufacturer has several alternative approaches:

- Have the product custom roll-formed by other companies
- Roll form it with the existing equipment
- Acquire a new roll forming line

12.2.1 Custom Roll Forming

To have a product manufactured by a custom roll former is a relatively easy decision. There are many reputable custom roll formers with suitable equipment to make the product once the product design and the anticipated volume are established. Slight design modifications suggested by the custom roll former can often reduce the price of the product and tooling. These modifications can either be general in nature or designed specifically to suit the product to the existing equipment of the custom roll former.

12.2.2 Roll Form with Existing Equipment

To roll form products with the customer's own, existing equipment is also a relatively simple decision, assuming that the equipment is suitable to form the product and enough manufacturing capacity is available. The decision can be more difficult if the mill does not have the capacity to form all of the required thickness and lengths.

12.2.3 Acquiring a New Line

The decision to buy a roll forming line is not a simple one. Capital investment can be significant, but on the other hand, the total sales value of the products manufactured during the first 20 to 25 year life of a good line is incredibly high. Therefore, purchasing an inappropriate line can cause difficulties.

Once the decision to acquire a roll forming line has been made, it is important to follow a few basic guidelines.

All aspects of the products to be roll formed must be considered. Some of the important parameters are: expected quantities in the first year; anticipated yearly and run quantities in the next 3 to 5 years; all variations of the products such as thickness, length, width, material types, tolerance, and appearance requirements; method of material handling; and packaging and availability of operators. Input from sales, marketing, production, inventory control, material handling, and other personnel can be just as important as the recommendations from the plant and financial management.

When all of the information is collected, it is highly recommended to have a "roll forming line specification" prepared by a person knowledgeable in roll forming. The 5 to 15 pages of the specification, depending on the complexity of the line, is a good basis from which to obtain quotations. The input of the suppliers should be taken into consideration and the specification modified if needed. The supplier's standard sizes, technology, and experience in the field can reduce the equipment, tooling as well as product costs without sacrificing quality. Suppliers can also recommend minor or relatively inexpensive changes to the roll forming line specifications, such as width of line, number of forming stations, and so forth that will make it feasible to utilize the new line to a greater extent. On the other hand, if only one product is to be formed on the line, then simplification and reduction in capital expenses are possible.

The updated "roll forming line specification" should be part of the purchase order and line acceptance test requirements.

12.2.4 Purchasing Used Line

A large number of roll forming mills, presses, and uncoilers are available most of the time at used machine dealers, auctions, or at the sellers' plant. It is not easy to find the exact line required, and compromises often have to be made. Used lines have no warranties, and drawings, manuals, and backups are frequently not available. Finding a line with the right tooling is also a rarity.

Financial considerations and quick availability are the main reasons of buying used equipment. Prices of the used machines depend greatly on their type, make, age, condition of the equipment, and market conditions. However, occasionally, good bargains are available. There are times that companies would pay high prices to get the equipment in order to market the product 5 to 6 months sooner than the anticipated delivery of a new line.

Before purchasing the used line, it is essential to check the line thoroughly and estimate the repair cost. Some used lines can be installed quickly and are ready for production, while others may require major maintenance and overhaul, which could cost more than the purchase price of the new equipment.

12.3 Evaluating the Product

To gain the most benefit from roll forming, it is highly recommended that the product be designed specifically for roll forming [342–345,347,348]. Products previously brake formed, press formed, extruded, or roll formed by others can usually be adapted to the new line, but the design should be reviewed in detail before equipment and tooling are ordered. Even minor modifications can reduce production cost or add to part strength and marketing features. Other design changes may permit incorporating secondary operations into the line to reduce product cost. Hence, not only should the cross-section be considered; all holes, notches, cutouts, embossments, welding, painting, and packaging should be appraised as well.

The selection of material for the product is affected by its application, strength, and price. Formability of the material, however, may influence the number of forming stands and thus the length of the mill. Type of paint or coating may have a bearing on roll tool material, surface finish, and lubrication specifications.

Product tolerance requirements can be important factors affecting the price of a new line. Length tolerances usually dictate the type of length measuring and die accelerating devices. Tolerances on section dimensions and appearance requirements influence the number of stands, and thus, the length of the line. Other tolerances such as location of holes, notches, straightness, and flare have a similar effect on price and size.

If the product is roll formed in different sizes, for example, different widths, or if different products are roll formed in the line in small run quantities, then it is important to reduce the changeover time. In these cases, quick changeover lines are recommended. On the other hand, if runs are long and the quantities are high, then a simpler single-purpose line may be sufficient.

To produce acceptable products, the roll shaft deflection must be kept within the specified limits. Shaft deflection is influenced by the shaft diameter and distance between the support bearings, the thickness and yield strength of the material to be formed, number of bends formed at each station, distance of bend lines from support bearings, type of forming (air bending or coining), as well as the gap between the upper and the lower rolls set by the operator.

A larger shaft diameter will reduce deflection and can improve product appearance and tolerances, but the tool material requirements for all future rolls will be higher (because tool weight is a square function of the diameter). Larger shaft diameters usually call for increased bearing and head sizes, horizontal distances, and consequently, a higher mill price. A larger mill, on the other hand, may be used for a greater variety of products and can extend the life of the mill.

12.4 Selecting Line Components

The roll forming line usually consists of four major parts; namely, the entry section, roll forming mill, cutoff press, and exit section, but auxiliary equipment and tooling may also be included.

12.4.1 Entry Section

A small percentage of all roll forming lines are manually or automatically fed with a precut sheet, or the product may be transferred directly from a previous operation such as piercing, notching, or brake forming. In most cases, however, the material is fed into the roll forming line in coil form.

Small lines may use coil cradles, but most coils are placed on uncoilers (reels). Occasionally, when small custom orders are produced, the partially used coils have to be removed from the uncoiler. However, most of the time, the coils are "run out" (used up). If the coil is usually runout, then it is economical to use the largest possible coil size to minimize coil handling and changing time. Maximum coil size is restricted by the capacity of material handling equipment and availability.

To utilize the potential of a roll former, it is important to keep the line running; in other words, minimize the nonoperating time. Because loading and threading the new coil takes usually the longest "nonproductive" time, the application of the double, rotating uncoilers, coil cars, turnstiles, or other material handling devices coupled with in-line storage of three to five coils and sometimes strip end joining (welding) are recommended. Productivity boosting equipment at the entry end can be fully utilized only if provisions are made to remove finished products without interruption at the exit end of the line. Mechanized product removal at the exit end can often greatly increase the output of the line.

An in-line coil accumulator, combined with strip-end joiner is the ultimate approach to continuous line operation. However, the high cost of the accumulators usually prohibits its use for roll forming lines, unless the continuous run is a technological requirement.

12.4.2 Roll Forming Mills

The mills can be classified in two basic categories; outboard or inboard types. In the outboard or cantilevered mill, the rolls are placed on shafts supported at one end only. Inboard mills have shafts supported at both ends, as described in details in Chapter 2.

Cantilevered shafts deflect more than those supported at both ends; therefore, outboard mills are usually used for thinner material and forming only the strip edges. The outboard mills have a great advantage for products with a variety of widths. Two outboard mills facing each other (duplex roll former) with at least one adjustable side can be set to different blank widths in about 1 min.

Inboard mills fall into several categories. The method of supporting the shaft (spindle) ends at the stands, the adjustability of the stands, tool interchangeability and variation in drive, and other features determine the type of mill.

Conventional, standard mills provide easy removal of outboard stands and access to change rolls one by one. However, changing to a new product may take 4 to 8 hr.

A variation of the conventional mill, supplied with outboard bearings matching the shaft diameters, permits moving the outboard stand closer to the inboard stand. This position reduces the shaft deflection.

Mills with universal coupler-driven shafts provide larger vertical shaft adjustments, which is required for deeper sections. It is also simple to disconnect the upper shaft drive if required. Mills equipped with universal couplers can be somewhat more expensive than conventional lines.

To increase roll forming line utilization, a variety of methods are offered to reduce the changeover time. In the case of "mechanically assisted" tool change applicable to conventional, universal, and other mills, the rolls are manually slid over to a pacifier shaft, which is also used to store rolls.

In other cases, the rolls are "locked-on" at the required position on the shaft. Removing the complete tooling with the shaft not only reduces the changeover time, but also makes the setup less dependent on the skill of the setup personnel, allowing improved repeatability of the cross-section. In an early "quick changeover" system, the shafts and the locked on rolls were removed or replaced in pairs. In most cases, the outboard stand had to be removed for this type of change.

The next more sophisticated (and more expensive) method was to replace rolls, shafts and bearings altogether. This required only disconnecting the drive and swinging the bridge out at each stand.

The above early technologies have been replaced with more advanced, subplated or rafted mills, which provide a considerably shorter changeover. Several stands, fastened to a plate (raft), complete with shafts and tooling can be removed together by a crane. It is expensive but a complete line changeover can take less than 30 to 45 min.

As an alternative to the shaft and tool changes, there are mills with multiple setup capabilities. The double high mill[1] consists of two independent sets of rolls at different levels. Changing the shape can be accomplished by feeding the material either to the bottom or to the top row of rolls.

Another simple and frequently used method to reduce changeover time is to install two or a maximum of three sets of rolls on each shaft. Each set has its own entry guide and straightener. The uncoiler and cutoff press remains in the same position, and the mill is moved sideways when the other set of rolls is operated.

Another approach to a double setup, especially for wider sections, is the "side-by-side" roll former.[2] With this type of equipment, two rows of stands, shafts, and tooling are mounted on one common base and driven by a common drive. The mill base can be moved sideways to line up the desired set of tools with the material feeding and runout sections.

One company has introduced a different approach to fast changeover [160]. Up to six sets of rolls, mounted on shafts, are cantilevered from a common turret type magazine. By rotating the magazine along the axis parallel to the direction of rolling, the desired set can be positioned. However, this type of mill has yet to gain widespread acceptance.

All but a few roll forming mills are driven by 2- to 200-hp electric motors. The horsepower is usually determined by experience — based on the number and size of stands, thickness and strength of material to be formed, depth of section, number of bends, rolling speed, and availability of coolant lubricant. An oversized drive increases initial capital expenditure and uses more energy than necessary. Undersized drives obviously limit the capacity of the mill.

Many older mills still in service are driven directly by less than a 20- to 30-hp motor. For 30-hp or larger motors, a clutch was normally applied to reduce power surges and shock on the line when jogging or operating with frequent stops and starts. Since the last decades of the twentieth century, variable frequency AC motors or DC motors have replaced these older methods.

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[1] Double high roll former is a registered trademark of The Bradbury Group.

[2] Side-by-side roll former is a registered trademark of The Bradbury Group.

When power is turned off or the clutch is disengaged, the product will still coast an average distance of 6 to 30 in. (150 to 750 mm), depending on the speed, type of line, type of material formed, friction, inertia of tooling, and other factors. If coasting is to be minimized, then a more positive stop has been attained. In the past, brakes stopped the drive train; lately the AC or DC motor controls the deceleration.

The early, simple, small mills usually ran at a single speed, while larger mills often featured multiple speeds. The change in speeds was either incremental (gearbox) or infinitesimal (often called “variable”). Most of the time, the variable speeds have been accomplished by mechanical devices and lately by electrical means. The advantages of variable speeds are simplicity and safety while threading a new coil end into the line, ability to produce short pieces, capability of improving length tolerance at lower speeds, and rolling heavier thicknesses without overloading the motor. If the line is coupled with a paint line, then plastic extrusion, welding, or similar operations where precise speed control is critical, the infinitely adjustable speed selection is imperative.

It is highly recommended that all mills be equipped with a coolant/lubricant system, even if at the time of procuring it, the first products to be roll formed do not require lubrication. No one can foresee what will be produced with the mill in the next 15 to 25 years and retrofitting a coolant/lubricant system is more expensive than ordering it with the mill. The properly applied coolant/lubricant will reduce tool wear and energy requirement, eliminate material pick-up on the rolls, improve surface appearance, and wash away dirt.

Inevitably, every plant manager wants space for a few more stands on the mill bed. Extra mill bed length is relatively inexpensive. It is recommended that in addition to the space required for the entry table and the other equipment, the mill bed should be ordered with extra space for at least two more stands than initially required.

12.4.3 Presses

The prepunch and cutoff presses are critical pieces of equipment in the line. Incorrectly designed or specified presses can be the cause of many shutdowns and problems. The presses should have the necessary capacity to punch, shear, notch, or emboss the maximum material width and thickness with the maximum shear strength at the maximum production rate. The stroke of the cutoff press should be long enough to cut the deepest section that the mill can produce. The presses should also have enough clearance between the posts to accommodate the widest die. Too little clearance between posts may result in weaker, inferior, or more expensive dies. It is recommended that the prepunching and cutoff presses and all the dies be designed for quick changeover. Operators should be able to change dies without removing the runout conveyor or other mechanisms around the press.

The presses can be powered mechanically, through clutch and brake, or pneumatically or hydraulically. Mechanical, underslung presses are most frequently used, but their limited strokes per minute capacity often represent the bottleneck of the line. Pneumatic presses operate faster and are lower in price, but they are too noisy, create excessive vibrations, and consume relatively expensive shop air. The new, fast acting, and quiet hydraulic presses are increasingly applied for both prepunching and cutoff.

12.4.4 Length Measuring

Length sensing and press triggering mechanisms are frequently part of counting and length predetermining systems. Electronic, microprocessor and computer controlled systems are taking a larger share of the market. These systems can also be used to govern other functions such as prepunching or producing a variety of patterns.

12.4.5 Finished Product Handling

The exit end of the line is often neglected in spite of the fact that the bottleneck created by the slow removal of the finished product affects the productivity of the whole line. At most roll forming lines, the finished product runs out on a steel roller conveyor table and is manually removed by the operator.

Belted conveyor tables are commonly used but they are not recommended for wide, heavy pieces, which have to be dragged sideway by the operator. For nestable building products or heavy structural sections, drop tables are often employed. Mechanized or computer-controlled product removal, combined with bundling and packaging, are available for many products.

Serious consideration should always be given to the removal of finished pieces or bundles to avoid interference with the productivity of the line.

12.5 Procuring Roll Forming Tooling

Without good tooling, the plant cannot produce good products at competitive prices. However, purchasing inferior tooling based on price alone is one of the most common mistakes made by the roll forming industry.

Supplying rolls is a competitive business. A supplier can reduce the tool price by reducing the quality of the tool steel, offering fewer passes, smaller roll diameters, avoiding side-roll stands or simply not meeting the customer's product tolerance, quantity, and quality requirements. Fewer passes, smaller "guide flanges" (not interlocking rolls and other shortcuts) can save a few thousand dollars at the time of purchasing but can result in tens or hundreds of thousands of dollar losses in increased setup time, increased scrap, reduced productivity, inferior product, and loss of customers. In extreme cases, after months of testing and scraping 40 to 50 tons of material, the complete set of rolls can end up in the garbage bin.

Pressing the tool supplier to reduce the number of passes is not recommended. Once the number of passes is established, it is wise to specify one more last pass, which does not do any forming. Two identical passes at the end provide better quality products.

12.6 Equipment and Tool Specifications

When new equipment and tooling is purchased, precise and detailed specifications prepared by a roll forming expert are highly recommended. The specifications should be discussed with the prospective suppliers prior to quotation. The supplier can provide good ideas or suggestions to reduce equipment, tooling, and product cost without scarifying quality or equipment/tooling life.

It is prudent to ask the supplier to provide a list of their recently supplied equipment and tooling, complete with contact names for checking references. The time and cost invested in the thorough preparation would only be a small fraction of the time and cost in correcting or solving problems that would ensue if inferior equipment and tooling are acquired.

Selecting reliable tool suppliers with experienced roll designers, is the primary requirement when rolls are purchased. The same rule applies to all other tools (cutoff, punching) and equipment (e.g., welding).

12.7 Acceptance Test

Acceptance test at the supplier's premises is preferred but it is not always feasible. The acceptance test requirements and procedures should be discussed with the supplier and be incorporated into the purchase order. It is highly recommended that the test should be carried out with the extreme material thicknesses, widths, and qualities specified in the purchase order. If only a single product is manufactured from one type of material, then coils from at least three different heats should be supplied for testing.

The acceptance tests are often late, behind schedule. Even then, it should not be rushed and shortcuts should not be taken. A few days of extra work and improvements can prevent a several years of headaches and loss of thousands of dollars.

12.8 Education and Training

12.8.1 Education and Training is a Key to Success

Every company can buy the same material at more or less for the same price as their competitors. Every company can buy the same equipment and tooling that was sold to other companies making the same or similar products. Some companies are flourishing and profitable, while others, in spite of these available opportunities, are struggling, loosing market share, and frequently have to be closed down. What makes the difference between winners and losers? It is the people that make the difference.

People, from the CEO down to the recently hired apprentices, people who develop and design the products, purchase the material, make decisions on the equipment and tooling, schedule the equipment, lay out the plants, maintain the equipment, but, most importantly, all the equipment operators and the supervisors, foremen, and plant managers, make the difference. If the people are knowledgeable and motivated, the company has an excellent chance of being successful. If they are not trained to do their jobs, then inefficient production, trouble, and squabbles are everyday occurrences. Therefore, if a company wants to be successful, then educating the people at all levels should be a basic requirement.

Mill operators as well as the plant supervisors should know how to setup and operate the new, sophisticated lines. Likewise, engineers should know how to design better products that can be produced at lower costs, purchase agents must be aware of new materials, and top executives must be familiar with the latest developments to select and justify better equipment than their competitors.

To setup the rolls personally and to operate the line for a few weeks is the best, but not necessarily a practical, approach to becoming proficient in all aspects of roll forming. The roll designer, who had to setup the rolls, will never forget the problems he/she came across. A part designer will be careful about where to locate the holes or cutouts and where to apply tolerances after trying to roll form parts to impossibly, and frequently unnecessary, tight tolerances.

Given the chance to setup and operate the lines, management personnel would probably appreciate more and consider the “operator friendly” features, easy and accurate adjustability, quality of the equipment and tooling, than the price alone when making decisions on equipment purchase.

Unfortunately, not everybody has the opportunity to setup and operate the roll forming lines. To counteract this problem, staff can be given the opportunity to attend roll-forming courses. They can update their knowledge and discuss problems with roll forming experts. Continuous education is essential because of the increasing rate of changes in the industry.

12.8.2 Roll Forming Line Operators

It is difficult to find formal operator training courses. Colleges, schools, and other organizations usually do not provide courses for roll forming line operators. Only a few, more advanced, companies arrange for organized training courses for their employees. Most mill operators remain attached to the “learn on the job” approach, which is not an easy task. New trainees have to learn the “tricks of the trade” by looking over the shoulder of other operators because the most experienced operators are either not qualified or incapable of training others. They will not explain to others why certain adjustments have to be made, or they are not willing to share their “hard earned” knowledge, fearing for their job security.

It is the responsibility of the company’s management to provide regular and organized training courses for the operators to improve their skills and to keep them updated on the latest technologies. During the courses, the operators should be acquainted with the principles of roll forming, understand the characteristics of different materials, learn about equipment and tooling, basic setup procedures, and elementary troubleshooting.

After the initial training, follow-up courses can be scheduled with more advanced training topics to teach the operators to setup all tooling, to operate all lines, and to troubleshoot the lines without or with minimum outside help.

Given that more and more additional secondary operation(s) and equipment are incorporated in the roll forming lines, it becomes necessary that operators should learn how to setup, operate, and troubleshoot all components of the line, including straighteners, feeders, presses, punching and notching dies, welders, sophisticated material handling and packaging equipment, computers, and other equipment. As a result of recent trends, roll forming line operators have to be trained as “Jacks of all trades.”

Good, knowledgeable operators can easily be motivated and be able to run the line with higher uptime and better utilization than nontrained operators. Well-trained operators will reduce the wear and damage to the tooling and equipment, and will contribute to lower manufacturing costs.

12.8.3 Maintenance Personnel

At many companies, maintenance personnel are also involved in the installation and start-up of new lines, moving and relocating equipment, and adding or retrofit components to the existing lines. A copy of the *Operating and Maintenance Manual* supplied with the line is usually kept by the maintenance department. The job description of the maintenance personnel varies from company to company, but the maintenance personnel, in addition to the regular maintenance functions, must be able to operate the roll forming line, setup the presses, the mill, and all the other equipment in the line.

The maintenance department is usually in charge of planning and carrying out the daily, weekly, monthly, and yearly maintenance of the lines, establishing a preventive (predictive) maintenance schedule, ordering replacement and spare parts, as well as repairing damages.

The countless varieties of mills, presses, controls, electrical, pneumatic, and hydraulic units impose a demand for maintenance personnel to have vast knowledge in many fields. The continuous changes in technology, methods, instruments, sensors, and equipment can make even an experienced maintenance mechanic outdated in a short time; continuously updating knowledge is thus necessary. Reading technical magazines and discussing equipment or parts with suppliers helps somewhat but it is certainly not sufficient. Management should provide opportunities for regular maintenance education in every field, including roll forming.

In addition to the basic updating of mechanical, hydraulic, pneumatic, and electric/electronic components, a typical roll forming line maintenance training program may cover the following topics:

- Basics of roll forming
- Components of roll forming line
- Installing and aligning roll forming lines
- Operations, methods of checking, and maintenance of
    - Uncoilers, flatteners, feeders
    - Roll forming mills (stands, drive train, entry guides, straightener, shoulder alignment procedure etc.)
    - Presses, tools and dies
    - Other equipment in the line
    - Lubrication
- Maintenance manuals of all equipment
- Maintenance schedules
- Safety

12.8.4 Setup Person, Line Supervisor, and Plant Manager

A good setup person can resolve most of the problems that are frequently beyond the capabilities of the operators. Because most of the setup persons' exposure to roll forming has been restricted to a few plants, it is advisable to expose them to other experts to acquire other methods and ideas.

The main responsibilities of the plant supervisors (lead hands, foremen, managers) are to deal with people and handle administration. However, a good supervisor must have adequate knowledge of roll forming in order to judge, guide, and supervise the operators. Plant supervisors frequently develop or contribute to new tooling and equipment requirements. To make the right decision, their knowledge must be extended beyond the plant in which they work. Exposure to product literature, sales personnel, and participation in roll forming courses can be very useful.

12.8.5 Product Designer

Manufacturing properly designed products is crucial to success. Often, small variations in design can make the difference between loss or profit. A good designer must know how the designed part will be manufactured. If the designer does not have the opportunity to operate a mill, then, as a minimum, he/she should visit the plant frequently, discuss problems with manufacturing personnel, and ask for their recommendations on manufacturability before finalizing the design and issuing the drawings. All the input from the plant personnel will influence the design, the dimensioning, and tolerancing of the part, which can be crucial to both the usability and the cost of the product. Chapter 14 identifies a number of important considerations; however, it cannot substitute firsthand experience and exposure to roll forming.

12.8.6 Purchase Agents and Schedulers

Material usually represents the largest percentage of manufacturing cost. Smart and resourceful purchasing, and occasionally substituting materials with the same quality metal but with different specifications, can often contribute to cost reduction. However, the possible cost involved in extended setup, scrap, increased assembly cost, or customer dissatisfaction must always be taken into consideration. Purchase agents, who had exposure to roll forming, are aware of the fact that the savings generated by procuring inferior quality material at a lower price can easily result in substantial loss for the company if the cheap material is not suitable for roll forming.

Scheduling of the lines has a great influence on their utilization and the productivity of the plant. For manufacturing purposes, usually long runs with minimum setup changes provide the best efficiency. However, long runs create a large inventory and longer intervals between product changes. On the other hand, marketing frequently requests “immediate” deliveries from the line; these requests often create more changeover time than running time. Schedulers frequently have to make a balancing act between these two contradicting demands. With a good knowledge of the operation of the line, the products, the equipment and tooling, the people, and the delivery requirements, a good scheduler can greatly contribute to the profitability of the company.

12.8.7 Managers and Executives

Top-level managers, who are making the decisions that will influence the operation and effectiveness of the plant, are usually the farthest away from the daily activities of the plant. Frequently, they make major decisions based on recommendations made by people who are not necessarily exposed to the newest and more efficient equipment and tooling available in the market. It is very important to discuss details with the operating personnel, but executives who have basic knowledge in roll forming will probably make better decisions than those who have not been exposed to daily operation of a roll forming plant.

Executives must also consider the future plans of the company, the possibilities of introducing new products, acquiring new plants and new equipment, plans for new layouts, material handling, methods, and equipment, which can all influence their decisions. They must also be aware of the advanced manufacturing methods to avoid buying new equipment based on outdated technology.

12.8.8 Tool and Equipment Designers

It is evident that the designers of the equipment, rolls, and tooling should know how the tool and the equipment operate, but frequently they do not. Many designers merely stay in the engineering office creating new designs without ever checking how the designed tool or equipment is built, installed, and operated.

Setting up, running, and troubleshooting the rolls can be the best education for a roll designer. These activities provide invaluable experience and advantage over other designers. Similarly, the equipment designers should operate the lines under plant conditions. This practical, hands-on experience will guide them to design the line to be more "operator friendly," which, in turn, will enhance the sale of similar equipment made by the company.

12.9 Motivation

It is not enough to have knowledgeable employees; they have to be motivated to efficiently and effectively apply their know-how. It is the task of the management to create and sustain a motivating environment. The CEO motivates the people directly working for him/her, who, in turn, must be able to motivate their subordinates and so on until all employees are involved.

Companies cannot succeed without knowledgeable and motivated employees in the competitive environment of the twenty-first century.

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13

Safety

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13.1 Safety

Worldwide, increasing emphasis is being placed on safety, as evidenced by the proliferation of safety standards such as the Occupational Safety and Health Administration (OSHA), American National Standards Institute (ANSI), Underwriters Laboratories (UL), and standards based on European Machinery Directives (EN).

In the United States, the OSHA Act of 1970 regulates the installation and use of machine guarding. In addition to OSHA, other organizations provide information on proper machine guarding. The ANSI publishes the B11 standards to provide information on the safety requirements for the construction, care, and use of machine tools. The National Safety Council's safety manuals and data sheets are good sources for safety of machine tools.

It is in the manufacturer's and user's best interests to understand and agree upon their legal and moral responsibilities regarding the safeguarding of machines.

Manufacturers want to produce a competitive machine, while users want a machine that increases productivity. However, before any of these goals can be met, both parties must first determine how to engineer the machine using safe design principles to minimize operator's risks.

Investing in a safer workplace will also reduce the expenses of treating injured workers, will help companies to control insurance premiums, prevent workplace accidents, and will help boost employee morale by conveying the message that the company cares about its employees and wants to protect their health and safety.

This chapter is intended to give the reader a brief overview of safety requirements for equipment, which are based on ANSI B11.12 and related standards.

13.2 Common Safety Related Definitions

Definitions listed here are based on B11.12 standards.

Safety is the ability of a machine to perform its function while being transported, installed, adjusted, maintained, dismantled, and disposed of under conditions of intended use specified in the instruction manual without causing injury or damage to health.

Risk is a comprehensive estimate of the probability and the degree of the possible injury or damage to health in a hazardous situation in order to select appropriate safety measures.

Hazard is a condition or set of circumstances that can cause physical harm to exposed personnel.

Danger zone is any zone within or around machinery in which an exposed person is subject to risk to his (or her) health or safety.

Operator is a person given the task of installing, operating, adjusting, maintaining, cleaning, repairing, or transporting machinery.

Pinch point is an area, excluding the point of operation, that poses a hazard by exposure to moving parts of the machine, its related machines or equipment, or the material being run.

Point of operation is the location in the machine where the material or a workpiece is positioned and work is performed.

Device is a piece of equipment or a mechanism designed to serve a special purpose or perform a special function.

Safeguarding is a method of protecting personnel from hazards arising from the use of guards, safety devices, or safe work procedures.

Guard is a barrier that prevents entry into the point of operation or other hazard area (zone).

Adjustable barrier guard is a guard with provisions for adjustments that will accommodate various jobs or tooling setups.

Awareness barrier is an attachment in which physical contact warns personnel of an approaching or present hazard.

Awareness device is a piece of equipment or signal that, by means of audible sound or visible light, warns of a present or approaching hazard.

Presence sensing device is a device that creates a sensing field, area, or plane to detect the presence of a part of a person's body.

13.3 Safety Design Procedure

The basic approach to controlling hazards is as follows in the order given:

1. Determine limits of the machine or system
2. Identify hazards/risk estimation
3. Risk reduction by design
4. Control the hazard by guarding
5. Warnings
6. Personal protective equipment
7. Training

13.4 Determining Limits of the Machinery or System

When eliminating hazards or reducing risks, both the user and manufacturer must first determine the intended use of the machine. This includes defining and discussing different machine operating modes, phases of use, and various intervention procedures for the operator. Speed, production, part sizes to be handled and produced, amount of automation, and auxiliary equipment should also be discussed.

To understand total space requirements for the safe operation of a line, one must include all of the auxiliary supporting equipment. This equipment includes pick and place mechanisms or destacker to feed blanks, and coil cars, turnstiles, or cranes to support the coil handling process. Also included are air compressors to supply compressed air to pneumatic mechanisms, hydraulic power units to support hydraulic function, robots, and automatic die change over equipment, and die carts to support the press functions.

Auxiliary equipment is an extension of the main line. Hazards are introduced if working space around such equipment is insufficient. Therefore, to ensure safety, it is very important for the manufacturer and user of the machine to take into account the space requirements for installation and range of motion of the system and its auxiliary supporting equipment. The designer should always predict the working life of the critical components and evaluate the hazards of those components under different modes of operation.

13.5 Determining Hazards/Risk Estimation

The next step in the process of a risk reduction program is hazard analysis; a process that identifies tasks associated with each stage of the machine's function and the hazards associated with these tasks. The best source for identifying hazards associated with the machine is to consult with those who are familiar with the operation of the machinery, for example, the operator, and safety and maintenance personnel.

Mechanical hazards associated with the metal forming industry occur in three basic areas as described in OSHA 3067, published by Department of Labor (see Figure 13.1 for examples of mechanical hazards).

The first area is the point of operation. This is where work is performed on the material such as uncoiling, slitting, cutting, roll forming, or bending.

The second area is the power transmission system. This includes all components of the mechanical system, which transmit motion, to the part of the equipment that does the work. These components may include pulleys, belts, connecting rods, chains, sprockets, or gears.

The third area is all other moving parts. This includes all other parts of the equipment, which move while the machine is in operation. These parts include reciprocating, rotating, or traverse moving parts, as well as feed mechanisms, conveyors, scrap choppers, and other auxiliary equipment.

Rotary motion is one of the most common motions found on coil processing equipment. Even a slow roll former can grab a glove or grip clothing, forcing a finger or arm into the danger zone. Forming dies, rotating pulleys, sprockets, and shafts are potential hazard points to watch for. Nip points are present at belts and pulleys, chains and sprockets, rack and pinions, and between multiple rotating rolls or gears.

Electrical hazards, thermal hazards, and hazards generated by noise and vibration that are nonmechanical should be included in hazard analysis.

Common hazards associated with the roll forming operations include handling blanks or coils with sharp edges or burrs, handling heavy rolls for set up, clearing jam ups, usage of the jog mode for threading coils, and testing rolls just to name few.

13.5.1 Risk Estimation

Risk estimation is a process whereby one makes a subjective decision (estimate of risk value) regarding the severity, probability, and frequency of an injury occurring in an unsafe condition. This process should be supported by qualitative and if possible quantitative methods.

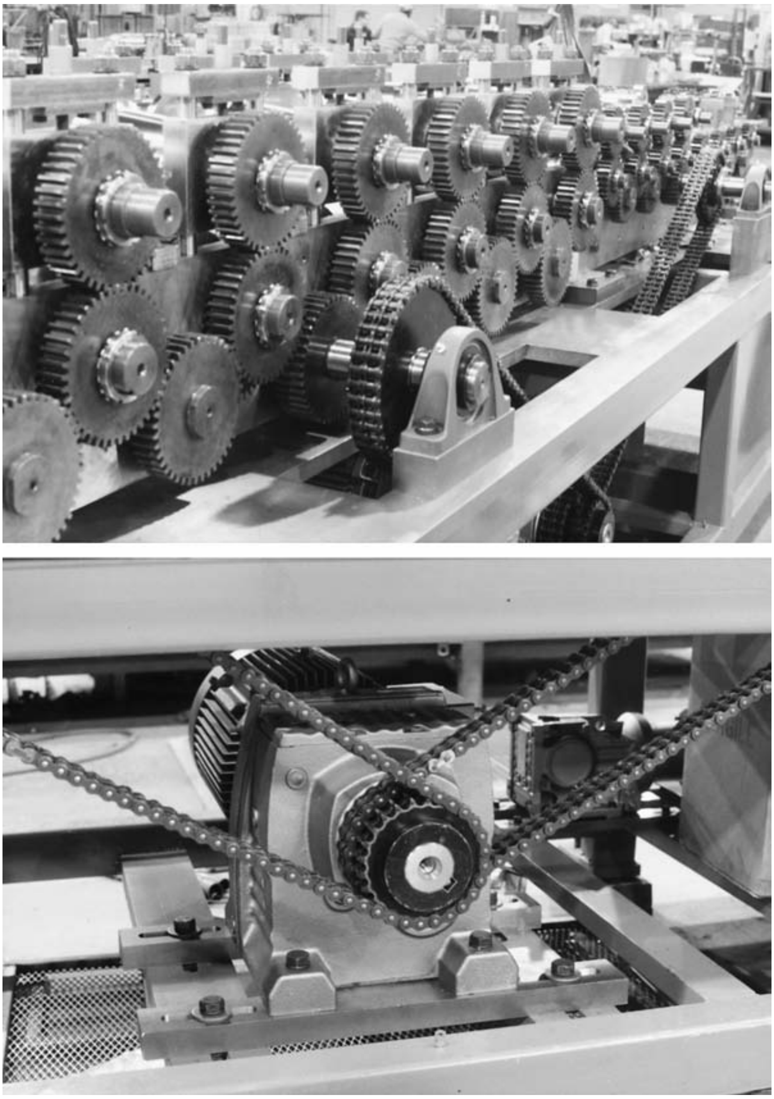

FIGURE 13.1 Examples of mechanical hazards.

Qualitative or quantitative judgments are based on the knowledge and experience of the decision maker in designing, operating, and understanding the history (accidents and problems) of the machinery. A quantitative method makes analyzing and selecting different safeguarding methods easier.

13.5.2 Risk Analysis Methods

Several methods are available for the systematic analysis of the aforementioned hazards. There are two basic types of risk analysis. One is called the "deductive method" (top down) and the other is the "inductive method" (bottom up). In the deductive method, the final event is assumed and the events, which could cause this final event, are then sought. In the inductive method, the failure of a component is assumed. The subsequent analysis identifies the events, which this failure could cause. EN1050 — Safety of Machinery, Annex B, describes these methods in detail, as outlined in the following summary:

Preliminary hazard analysis (PHA) is an inductive method whose objective is to identify a hazard that can cause harm, which could lead to an accident.

Hazard and operability study (HAZOP) is a systematic technique to detect probable deviation, from normal operation, that could lead to hazardous events.

The "what if" method reviews each process and "what if" questions are formulated and answered to evaluate failure of the components.

Failure mode and effect analysis (FMEA) is an inductive method where the main purpose is to evaluate the frequency and consequences of component failure.

The DEFI method uses a computerized system, where faults are recorded to determine rate of failure.

The method organized for a systematic analysis of risks (MOSAR) is a complete approach to evaluate failure of the system.

Fault tree analysis (FTA) or event tree analysis (ETA) can be either a qualitative or a quantitative model of all the undesirable outcomes, which could result from a specific initiating event. Probabilities are assigned to each event and then used to calculate the probability of occurrence of the undesired event.

The DELPHI-technique is a forecasting method, which is also used in generating ideas.

13.5.3 Risk Evaluation

Risk evaluation is a process in which one asks simple questions for each hazardous condition and then answers those questions to be evaluated. Questions asked are: If there is an accident, how severe can it be? How often and how long will the operator be exposed to this unsafe condition? In addition, what is the probability of occurrence and possibility of avoiding this accident in the future?

Risk value is a cumulative estimate of individual answers to the above questions.

1. The severity of potential injury

Fatal	Death	S4
Major (normally irreversible)	Amputation	S3
Serious (normally reversible)	Burns, breakage	S2
Minor	Bruises, cuts	S1

2. Frequency and duration of exposure

Frequent	(Several times a day or more)	F3
Occasional	(Daily)	F2
Seldom	(Once a week or less)	F1

3. Probability of occurrence of injury

Certain	P4
Probable	P3
Possible	P2
Unlikely	P1

Experience has shown that these parameters may be combined to give a graduation or risk on a weighted scale, for an example, 1 to 8 (1, 2, 4, and 8), for severity of potential injury, 1 to 6 (1, 3, and 6) for frequency of exposure, and a scale of 1 to 12 (1, 4, 8, and 12) for probability of occurrence of injury. The weighted scale and values assigned can vary and are usually based on the decision maker's judgment. In this example, a cumulative risk value of 26 is assigned for the worst case scenario.

Example

In roll forming, a nip point is present between the entry table, material and forming rolls.

To assess the risk created by this nip point, the hazard should be evaluated assuming that no guard is installed on the machine.

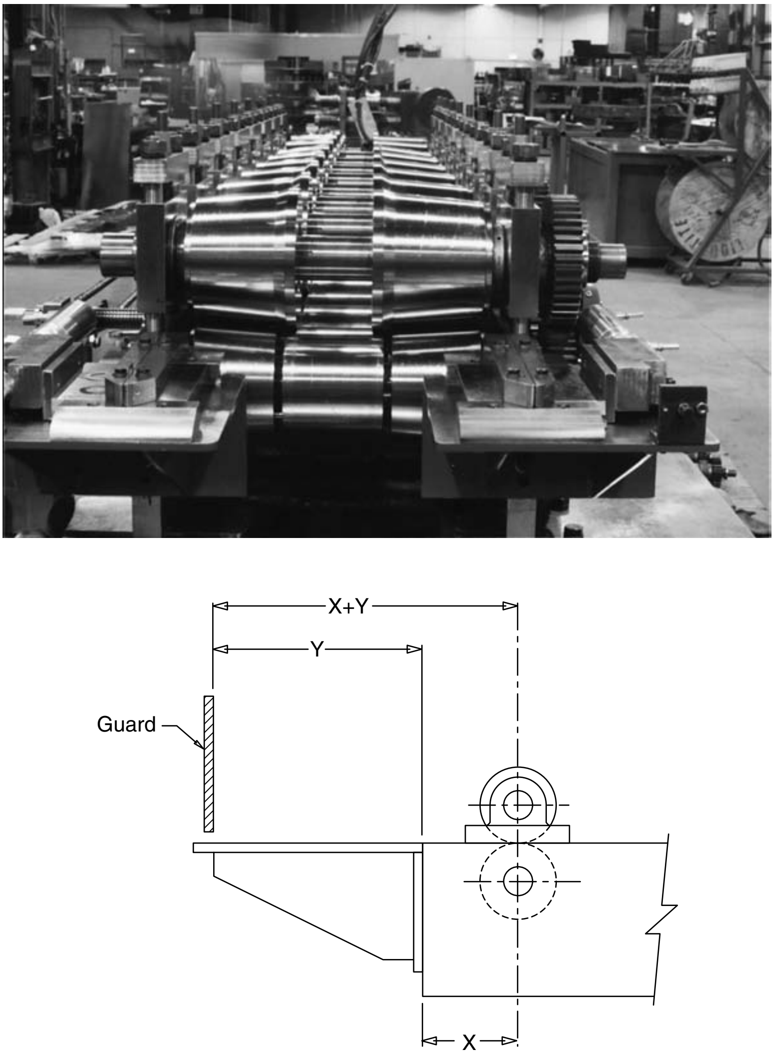

FIGURE 13.2 Nip point. Assoc of Manufacturing Technology.

A nip point at the entry to the roll former will have:

The severity of potential injury	Major	S3(4)
Frequency of exposure	Frequent	F3(6)
Probability of occurrence of injury	Probable	P3(8)

When designing a roll former, the location of the first station is X distance away from the end of the entry table. By placing the guard Y distance (other direction) from the end of the entry table, the total distance that the guard will be from the nip point is $(X + Y)$. See Figure 13.2.

Guarding by means of a fixed guard is considered one of the main ways of protecting personnel from point of operation hazards in roll forming. These guards must be designed to protect an operator's fingers or hands from reaching through, over, under, or around the guard to the point of operation. Any access through the guard must conform to Figure 13.3. (1910.217 Table 0–10), published by OSHA, and to Figure 13.4 and Figure 13.5, published by Liberty Mutual Insurance Company.

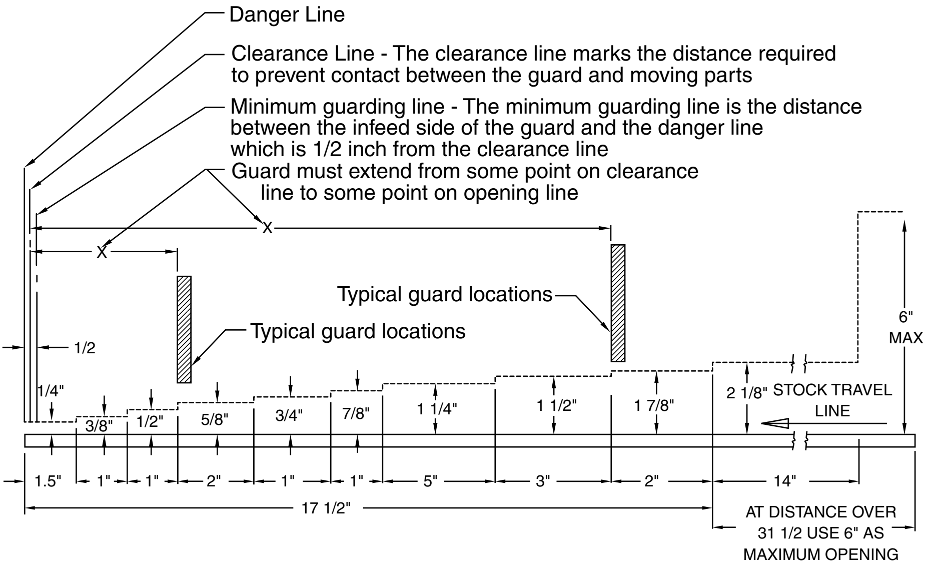
Danger Line
Clearance Line - The clearance line marks the distance required to prevent contact between the guard and moving parts
Minimum guarding line - The minimum guarding line is the distance between the infeed side of the guard and the danger line which is 1/2 inch from the clearance line
Guard must extend from some point on clearance line to some point on opening line
X
X
Typical guard locations
Typical guard locations
1/2
1/4"
3/8"
1/2"
5/8"
3/4"
7/8"
1 1/4"
1 1/2"
1 7/8"
2 1/8"
STOCK TRAVEL LINE
6" MAX
1.5"
1"
1"
2"
1"
1"
5"
3"
2"
14"
17 1/2"
AT DISTANCE OVER 31 1/2 USE 6" AS MAXIMUM OPENING

FIGURE 13.3 OSHA, 1910.217, Table 0–10. Liberty Mutual Group.

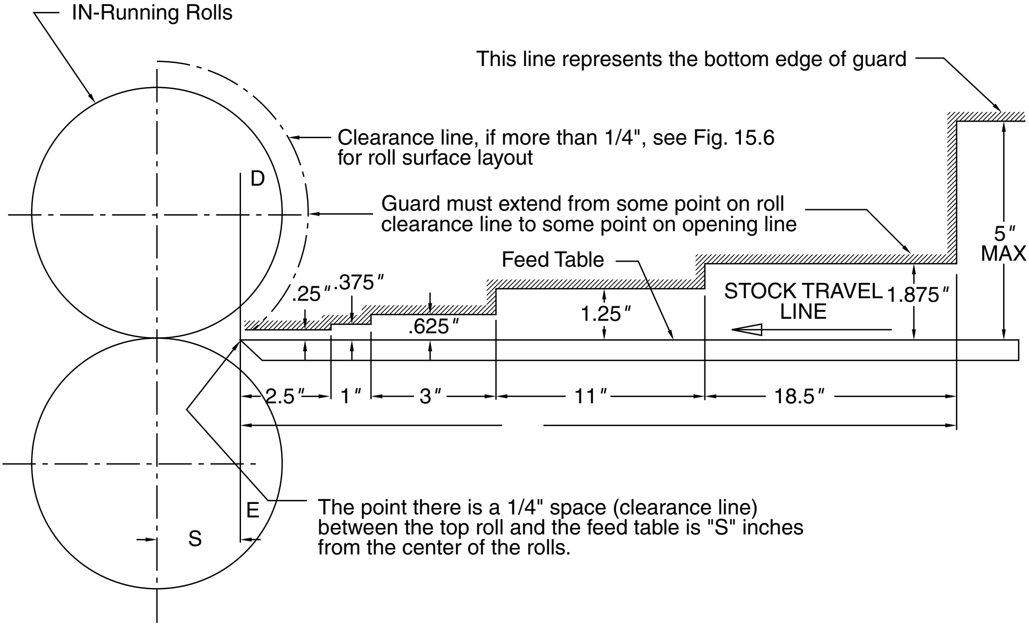
IN-Running Rolls
This line represents the bottom edge of guard
Clearance line, if more than 1/4", see Fig. 15.6 for roll surface layout
D
Guard must extend from some point on roll clearance line to some point on opening line
Feed Table
5″ MAX
.25″
.375″
.625″
1.25″
STOCK TRAVEL LINE
1.875″
2.5″
1″
3″
11″
18.5″
E
S
The point there is a 1/4" space (clearance line) between the top roll and the feed table is "S" inches from the center of the rolls.

FIGURE 13.4 Liberty mutual standard drawing 2110. Liberty Mutual Group.

Let us assess the risk once again, as the nip point is $(X + Y)$ distance away

The severity of potential injury	Minor	S1(1)
Frequency of exposure	Seldom	F1(1)
Probability of occurrence of injury	Unlikely	P1(1)

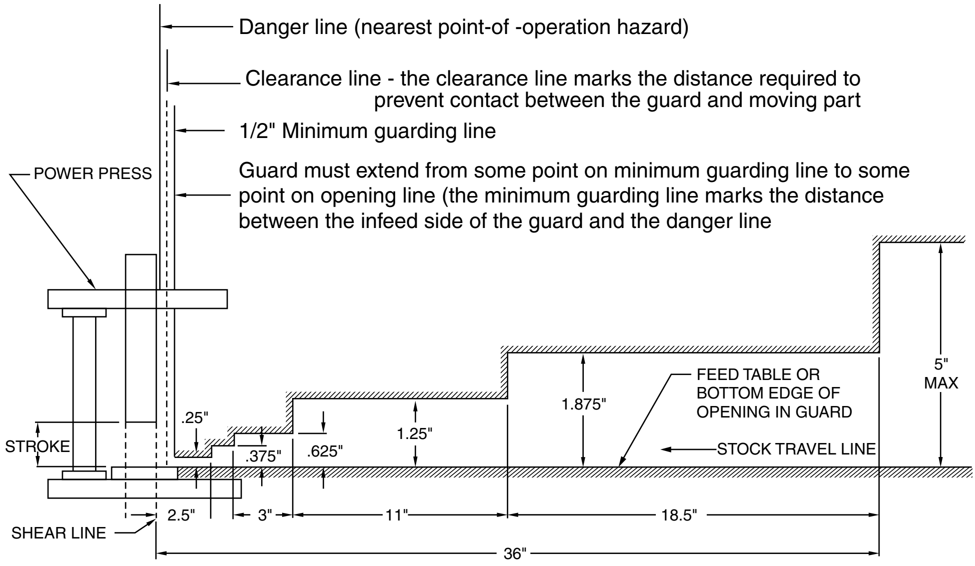
Danger line (nearest point-of -operation hazard)
Clearance line - the clearance line marks the distance required to prevent contact between the guard and moving part
1/2" Minimum guarding line
Guard must extend from some point on minimum guarding line to some point on opening line (the minimum guarding line marks the distance between the infeed side of the guard and the danger line
POWER PRESS
STROKE
SHEAR LINE
.25"
.375"
.625"
1.25"
1.875"
FEED TABLE OR BOTTOM EDGE OF OPENING IN GUARD
STOCK TRAVEL LINE
5" MAX
2.5"
3"
11"
18.5"
36"

FIGURE 13.5 Liberty mutual standard drawing 2063.2.

Initially, without the guard, the total risk was at level 18, (medium risk hazard). The same hazard, with redesign and a fixed guard added has a total risk level of 3 (minor risk hazard).

Next, ascertain the potential hazards and hazardous situations associated with modes of operation or tasks performed by the machine and assigned total-risk values. Each hazard or task is then evaluated with the objective of either eliminating the hazard or reducing the risk to a tolerable level by first attempting to eliminate it by design and if this is not possible or not satisfactory reduce the risk by the use of safeguarding techniques.

13.6 Risk Reduction by Design

Risk reduction by design means using safe design principles, utilizing automation and devising work procedures to minimize personnel exposure to hazards. ANSI B11 TR3-2000 “Risk assessment and reduction — A guideline to estimate, evaluate and reduce risk associated with machine tools” describes these principles in detail, as outlined in the following summary:

(1) A machine should be designed considering all aspects of day-to-day operations. Hazard analysis will guide the designer to apply sound design principles during the design cycle to minimize the operator exposure to hazard. Some examples are listed below.
  - Remove any sharp edges, sharp angles, or rough surfaces of the parts of the machinery.
  - Use a larger safety factor during design.
  - Reduce speed, noise, and vibration and avoid extreme temperatures.
  - Follow industry codes and standards.
  - Select the right material and heat-treat processes.

(2) *Apply ergonomic principles.*
Refer to ANSI B11 TR1-1993 ergonomic guidelines for the design, installation, and use of machine tools.
  - Avoid stressful postures and movements during use of the machine.
  - Increase safety by reducing stress and physical effort of the operator.

- Provide proper lighting.
- Design, locate, and identify manual controls so that they are clearly visible, identifiable, and safely operated.
- Design and locate indicators, dials, and visual displays to enhance safety and operation of machine.
- The manufacturer must take account of the constraints to which the operator is subjected because of the necessary or foreseeable use of personal protection equipment.

(3) *Apply sound safety principles when designing control systems.*
Insufficient attention to the design of machine control systems can lead to unforeseen and potentially hazardous machine behavior.
  - The control systems must be designed and constructed so that they are safe and reliable. Control reliability is a design philosophy to assure that a given circuit will perform as expected, despite the failure of any single component in the system.
  - Controls for setup and maintenance modes must be designed using ergonomic principles and applicable electrical standards to ensure operator safety.
  - The machine must not be capable of starting up unexpectedly and should have one or more emergency stop devices. The failure of the power supply or control circuit must not lead to a dangerous situation.

(4) *By introducing automation*:
  - Skew conveyors, destackers, or feeders are used in the operation to automate feeding into the roll former. These devices will limit the risk by reducing hazards at the operating points.
  - The need for access to danger zones can be minimized by locating maintenance, lubrication, and adjustment points outside of these zones.

(5) A jog mode is provided to thread the coil through processing equipment to test tooling. Here, the operator is exposed to point of operation hazards. To reduce risk, the following items should be implemented:
  - Only the operator should have control over the jog operation.
  - The machine must be jogged at very slow and controlled speeds.
  - The jog actuator should be designed so it cannot be actuated accidentally.
  - Unplanned maintenance, jam clearing, and minor tool changes require proper training.

(6) Large coils require special handling while loading on to an uncoiler and while threading through the processing equipment. A coil car, coil car upender, hydraulic expansion, or overarm hold-downs should be used to make this operation safe.

(7) Usually, the guides to feeders, presses, and roll formers are set for a particular width of a coil. Camber, oil-canning, and improper slitting can produce variable widths on a single coil causing a jam up at the entry guides, creating an unsafe situation. To avoid this, spring-loaded gauge bars, which adjust automatically to width variations, are recommended. Electronic sensors are also used to detect unacceptable width changes and double feed of the part, and to warn the operator of these problems.

(8) Whenever dies are being adjusted or repaired while in a press, die safety blocks must be used per OSHA subpart O, 1910.217(d)(a)(IV). To avoid accidentally striking the press or leaving the safety block in the press after use, an electrical power cutoff interlock system should also be used.

13.7 Safeguarding

Safeguarding devices to be used to protect persons (production operator, personnel in charge of setting, teaching, or maintenance personnel) from the hazards, which cannot reasonably be avoided or sufficiently limited by design. The level of remaining risk will determine the level of safeguarding.

Two broad categories of safeguarding methods are available to protect the operator from hazards created at the point of operation of the machine.

- The first method is the use of barrier guards, which prevents access to the point of operation or other hazards but will not allow operators to feed parts into the point of operation manually.
- The second method is the use of protective devices, which keeps the operator or other personnel from being injured at the point of operation.

13.7.1 Types of Barrier Guards

A fixed guard is kept in place permanently with fasteners, making removal or opening impossible without using tools. Figure 13.6 shows a fixed enclosure guard shielding the sprocket and chain on a conveyor.

Fixed guards:

- Must be securely held in place.
- Can be opened only with tools.
- Adjustments, lubrication, and maintenance points must be located outside of the danger zones.
- Must allow adjustments, maintenance, repairs, cleaning, and servicing operations to be performed while machinery is at a standstill. Examples include guards made from expanded metal, solid metal, Lexan®, or Plexiglas®.

Interlocked guards will trip a mechanism that shuts off power when they are opened or removed so that the machine cycle cannot be started until the guard is back in place.

Movable guards can be opened without the use of tools and some standards require that they also be interlocked.

An interlocking guard with the guard locked must be closed and locked to allow the machine to operate.

An adjustable guard is one to which once adjustments are made, and remains fixed during a particular operation.

An adjustable guard on a power press can be modified according to the thickness of the material being run. It provides a barrier that may be adjusted to facilitate a variety of production operations.

Figure 13.7 shows a self-adjusting guard on circular saw. It provides a barrier that moves according to the size of the stock entering the danger area.

A control guard initiates the operation of machinery after it is closed.

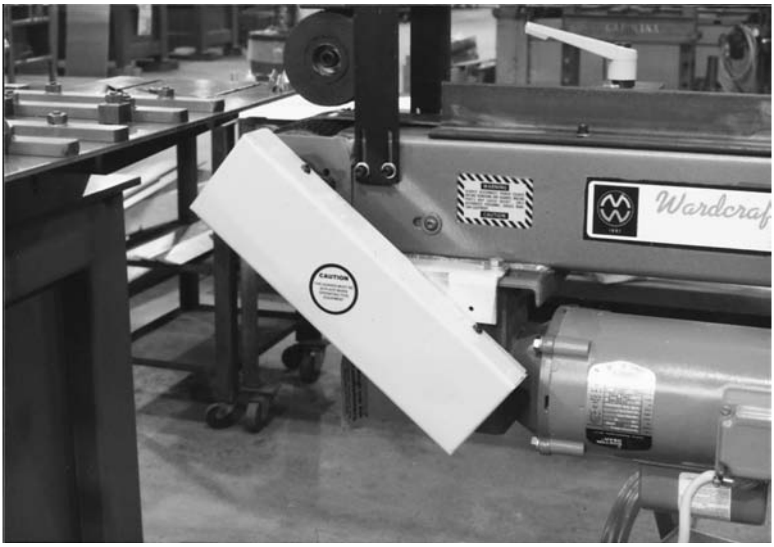

FIGURE 13.6 Fixed enclosure guard on a conveyor.

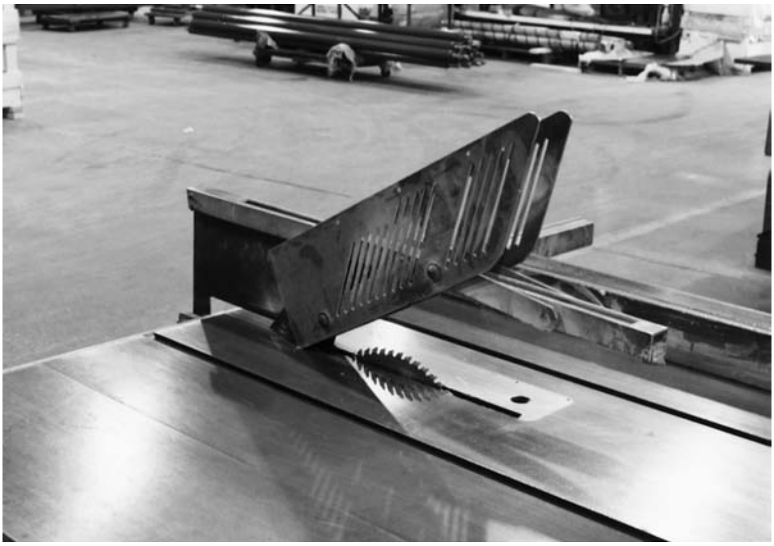

FIGURE 13.7 Self-adjusting guard on circular saw.

13.7.2 Types of Protective Devices

An interlocking device, as used with a guard, can be mechanical or electrical. The purpose of this type of device is to prevent the operation of the system under certain conditions.

An enabling device is a manually operated device, which, when continuously activated in one position only, allows unsafe conditions but does not initiate them. In any other position, unsafe functions are stopped safely.

A hold-to-run control device is a manually actuated start and stop control device, which initiates and maintains operation of machine elements only as long as the control is actuated in a set position. The control automatically returns to the stop position when released.

A two-hand control device requires simultaneous actuation by the use of both hands in order to initiate and maintain the operation of the machine element in which the unsafe condition exists. This kind of control requires a part revolution clutch, brake, and a brake monitor if used on a power press. With this type of device, the operator's hands are required to be on the control buttons and at a safe distance from the danger area while the machine completes its closing cycle.

A trip device causes the machine to stop when a person or part of their body enters an unsafe limit. Safety trip controls provide a quick means for deactivating the machine in an emergency. The trip device may be mechanically actuated. Examples include trip wires, pressure sensitive devices, or nonmechanically actuated devices such as a photoelectric device.

A mechanical restraining device uses a mechanical stop to prevent unsafe motion. Pullback devices utilize a series of cables attached to the operator's hands, wrists, or arms. This type of device is primarily used on a machine with stroking action. Examples include power presses and press brakes.

The restraint device utilizes cables or straps that are attached to the operator's hands and a fixed point. Hand-feeding tools are necessary if the operation involves placing material into a danger area.

A limited movement control device is a control system, the operation of which permits only a limited amount of travel of a part of the machinery on each occasion that the machinery is precluded until there is a subsequent and separate actuation of the control. This serves to minimize risk as much as possible.

A deterring/impeding device is any physical obstacle which, without totally preventing access to a danger zone, reduces the probability of access to this zone by offering an obstruction to free access.

Pressure sensitive safety mats guard the floor area around a machine. Typically used with flexible manufacturing cells or robotics cells, it is intended to be used as an auxiliary safeguarding device.

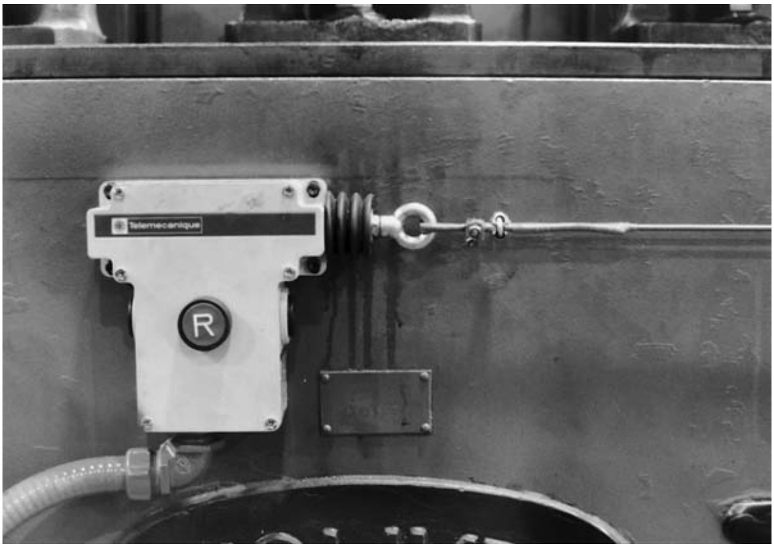

FIGURE 13.8 Cable pulls switch.

Pressure sensitive edges are attached to moving parts. On contact, a flexible sensitive edge is depressed sensing a stop signal to the controller.

Emergency stops are intended to reduce existing hazards to persons, damage to machinery or work in process. This to be initiated by single human action when the normal stopping action is inadequate for this purpose. Examples include emergency stop buttons and grab-wire switches.

13.7.3 Cable Pull Switches

Cable pull switches are cables of braided or plastic-coated wire, horizontally installed across the points of hazards created by rotating machinery, conveyor motion, and so on. See Figure 13.8.

1. They are located at the point of hazard for use by the operator involved.
2. The cable is made slack by pushing or pulling. A stop signal then stops the guarded machine. The safety contacts must remain open until the cable is returned to a safe state and the switch is manually reset, allowing operation of the machine.
3. Refer to OSHA 1910.216 code for design details.

13.7.4 Presence Sensing

1. A photoelectric light curtain should be used on a machine, which can be stopped before the worker can reach the danger area. This device uses a system of light sources and controls, which can interrupt the machine's operating cycle.
2. Radio frequency (capacitance) presence-sending devices use a radio beam that is part of the machine control circuit. When the capacitance field is broken; the machine will stop or will not activate.
3. Electromechanical sensing devices have a probe or contact bar, which descends to a predetermined distance when the operator initiates the machine cycle. If there is an obstruction, preventing the bar from descending to its full-predetermined distance, the control circuit does not actuate the machine cycle.
4. Refer to OSHA 1910.217(c)(3)(iii) code for design details.

13.8 Selection of Guards and Protective Devices

The exact choice of safe guards for a machine should be made based on the risk assessment for that machine.

A fixed guard is simple and should be used where access by an operator to the danger zone is not required during normal operation. As the need for access increases in frequency, the inconvenience resulting from removing and replacing a fixed guard increases until another method is required. In this situation, an interlocking guard, self-locking guard, trip device, or combination of these can be selected as a safeguarding method.

When access to the danger zone is required during normal operation, an interlocking guard, trip device, adjustable guard, self locking guard, two-hand control device, or control guard or combination of above can be selected as a safeguarding method.

The present trend for a common line is:

Uncoiler	Fixed guard
Leveler/straightener	Fixed guard at point of operation
Press (precut/postcut)	Full protection at the point of operation and around the press
Roll former	Fixed guard, interlocking guard, cable pull switches or emergency stops
Conveyor	Fixed guard

Auxiliary safeguarding, in conjunction with a primary safeguarding device, should be used when additional hazards are introduced and when multiple machines are used in a system. For example, auxiliary equipment like a coil reel, straightener, or a roll feed is used with a power press. Refer to ANSI B11.20-2004 “Safety requirements for manufacturing systems/cells” for the safety of multiple machines under some type of common controls. Fixed guards, pressure sensitive mats, light curtains, trip switches, cable pull switches, or presence-sensing devices can be used in this application.

13.9 Required Characteristics of Guards and Protection Devices

In designing safeguards, the type of guard or protective device and their method of construction should be selected to take account of the machine characteristics that may cause injuries to the machine operator. Guards and protective devices shall be compatible with the working environments of the machine, and designed so that they cannot be easily defeated. They should provide the minimum possible interference with activities during operation and other phases of machine life.

General requirements of guards and protection devices

They should:

1. Be of robust construction
2. Not give rise to any additional risk
3. Be located at an adequate distance from the danger zone
4. Cause minimum obstruction to the view of the production procedure
5. Enable essential work to be carried out during installation or replacement of tooling and during maintenance, by restricting access only to the area where the work has to be done, if possible without the guard or protective device having to be dismantled
6. Not be easy to by-pass or render inoperable
7. Prevent contact and eliminate the possibility of the operator or another worker placing parts of their bodies near hazardous moving parts
8. Create no new hazards or interference
9. Allow safe lubrication.

13.10 Signals and Warning Devices

Wherever necessary (but not as a substitute for elimination by design or the use of safeguards), the designer may add warning signs and devices.

Visual signals, such as flashing lights and audible signals (e.g., siren, horn, etc.) may be used to warn of an impending hazardous event such as machine start-up or overspeed.

Markings, signs, and written warnings should be readily understandable and unambiguous. These signs concerning the specific function(s) of the machine, as they are related to readily understandable signs (pictograms), should be used in preference to written warnings.

In the United States, labels should be designed using ANSI Z 535-1,2,3 and 4-1991 standards.

Label(s) must have:

1. Proper use of color
   Use:
   - Safety Red to identify danger and stop
   - Orange to identify warning signs (hazardous part of the machine)
   - Safety Yellow to identify caution signs
   - Safety Green for the identification of safety, emergency egress, and the location of first aid and safety equipment
   - Safety Blue for the identification of safety information used on informational signs and bulletin boards
2. Use of symbols and pictographs
   - Danger suggests "will result in severe death or injury"
   - Warning suggests "could result in severe death or injury"
   - Caution suggests "may result in minor or moderate injury"
3. The message should identify the hazard
4. Notify result of ignoring the warning and suggest how to avoid imminent hazards

13.11 Personal Protective Equipment

To provide adequate protection, the protective clothing and equipment selected must always be best for the situation. Refer to ANSI Z244.1-1982 code for more details.

Eye protection	Protects from spills or flying objects
Hearing protection	Protects from loud machines
Breathing apparatus	Protects from chemical and toxic environment
Special clothing	Protects from cuts, brushes, and heat
Hard hats	To avoid bumps and falling objects
Caps and hairnets	To keep the worker's hair being caught in the machine
Safety shoes, boots	Protects feet from heavy falling objects

It is important to note that protective equipment itself can be hazardous. A glove can be caught between rotating parts, safety goggles may hinder vision, or loose cloth or jewellery can catch on a machine part. That is why training on how to use a protective device safely is very important.

13.12 Training

To complete the process required by the supplier, technical manuals and drawings must be generated to provide the necessary information to the users regarding proper operation and maintenance of the machine and its associated equipment.

The user in turn must utilize the information, to ensure that the minimum amount of risk is maintained. The user should conduct his own risk assessment based on the anticipated tasks and together with recommendation from the supplier, develop a safe working procedure, and train the operators on the proper use of the machinery.

Standard lockout/tagout procedures depend upon procedures to protect workers. When a machine is to be shutdown for maintenance, the energy (electrical, mechanical, pneumatic, and hydraulic) must first be isolated and disconnected. Refer to OSHA 20 CFR 1910.147 for lockout/tagout standards.

Owing to heat and friction created in the process, galvanizing sheet has the tendency to build up (zinc flakes) on the rolls. Over time, if rolls are not cleaned, then the build up of zinc film can damage the quality of part. The tendency of the operator is to clean the rolls while they are turning. This tendency creates a very high-risk hazard. The designer should incorporate a stock lubricator to lubricate the tooling, which decreases the build up of coating and reduces the frequency of roll cleaning. When cleaning must be done, always remove the rolls from the machine for cleaning.

In stamping and operations, the following instances are where training is very critical for safe operation:

- During winding of the coils, the innermost coil wrap has tendency to become damaged. When this damaged section is fed through a feeder or press, the probability of a jam up is very high, causing an unsafe condition. Sensors are used to detect the trail end of the coil, signaling the operator to take proper steps. Proper training is essential to unjam the metal safely.
- Depending on the size of the roll mill, forming rolls can be very large and heavy. The operator should use a lifting device to assist him in removing or installing rolls or back injury, a pinched finger, or foot injury can occur.
- All precut sheet metal blanks have sharp edges and can cause cuts and bruises if not handled properly. The operator should be trained to use proper protective equipment to handle raw material and finished parts.
- Setting the rolls for a given material thickness is a critical function. The operator becomes exposed to an unsafe condition working next to the rolls without guards. It is critical for the users to provide necessary training to limit the risk.
- Lubricant spills around the line create a dangerous situation. Proper housekeeping guidelines will help to reduce unsafe conditions.

13.13 Summary

In summary, machine safety requires:

1. Designing and building machinery with the primary intention of making the machine as safe as possible.
2. Using safeguarding devices to avoid operator entry into the hazard area.

   The determining factor in deciding how best to protect workers from potential hazardous machinery is contained in OSHA 1910.212 (3) ii: “The guarding device shall be in conformity with any appropriate standards or in the absence of applicable specific standards shall be so designed and constructed as to protect the operator from having any part of his body in the danger zone during the operating cycle.” It is the manufacturer and user’s responsibility to understand these rules and regulations and to consult the governing standards when clarity is needed.
3. Informing the operator of any potential hazard(s), if any, while operating the machine by the use of warning signs.
4. Informing the operator of the usage of protective devices while operating the machine.
5. Providing without any ambiguity safety manuals detailing the proper use of machinery.
6. Implementing a safety/training program for all personnel operating and maintaining the system.

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14

Increasing Efficiency of Roll Forming Lines and Case Studies

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George T. Halmos
Delta Engineering Inc.

14.1 Output, Productivity, and Efficiency

The output of a plant or a production line can be measured by the number of units produced in a given time period. The output can be increased by working overtime, using additional shift(s), or adding more equipment and operators, but these actions will not change significantly the unit cost of the product. Frequently, the unit cost will slightly increase, for example, when paying premium for working overtime, other times it can modestly decrease.

Productivity on the other hand is measured by the number of units produced per operator in a given time. The most common unit to measure productivity is the output per person-hour. The output can be measured in number of pieces, weight, length, covered area, value, or other units. In the roll forming industry, the most practical way is to measure the output of a line in length units (feet, meters), or occasionally by the number of pieces produced per production line or per person per shift.

The traditional but not necessarily the best way to measure productivity is to establish production standards by time studies or other methods. These standards reflect the average output that can be achieved by the operators without extra effort and are usually considered as the "norm" or 100%. The standards are based on past experience, and in the case of roll forming, they include the accepted "nonproductive" times, such as coil change, removal of finished products, checking quality, completing administrative, and other tasks.

Comparing the actual output with the "standard" can lead to contentment. Plants regularly achieving 100, 105, or 110% of the standard consider themselves efficient. This attitude can lead to complacency and does not provide incentive to look for further improvements.

Measuring the utilization of a line is a much better way to judge efficiency and it leads the way to productivity improvements. Continuous increases in productivity are essential to remain competitive and are a key element to the success, profitability, and growth of every company.

14.2 Line Utilization

A line is theoretically fully (100%) utilized if it roll forms products nonstop, full time, at the maximum possible speed. Of course, in real life, it is not expected that a line will run nonstop all the time, but the closer the actual running time is to 100%, the better. Even the "continuously running lines," like tube mills — roll forming mills with extrusions or foam filling operation — stop once in a while for product change, maintenance, or other reasons. Most roll forming mills are also idle for additional reasons, for example, for coil change and other activities.

An actual case described here highlights the difference between working to standards and line utilization. An older, roof deck roll forming line was regularly running at 100 to 110% of the standard established by time studies. The management was satisfied and not much effort was put into further improvements until they were challenged by their first "computer expert" who pointed out the following:

- The line produced 57,000 ft (17,375 m) of roof decks in 2 shifts (16 hr)
- The line was running at its maximum speed of 180 ft/min (55 m/min)
- The maximum capability of the line was 180 (ft/min) × 60 (min/hr) × 16 (hr) = 172,800 ft (52,670 m).

The actual line utilization during above described production run was

$$\frac{\text{Actual Production}}{\text{Max Mill Capacity}} \times 100 = \frac{57,000}{172,800} \times 100 = 33\%$$

Furthermore, the line was running one profile for 16 hr, followed by an 8-hr tool change to another profile. The line was idle during the tool change. Therefore, the real line utilization during this 16 + 8 hr period was

$$\frac{57,000 \times 100}{180 \times 60(16+8)} = 22\%$$

The management was taken aback at first, but soon realized that when the running time of the 20,000-lb coil is about 15 min and the coil change takes 15 min (approved standard at that time) then this nonproductive coil change alone reduces the line utilization to 50%. Action was taken immediately to find out what happened during the unproductive times, at the time when the line was not running.

Time studies revealed that this and the other lines were stopped for the following reasons:

- Feeding in coil ends or attaching the leading end of the coil to the tail end of the processed coil
- Changing coils or positioning new loads of sheets or strips
- Setting and changing of lengths
- Inspecting dimensions and other checking quality
- Adjusting equipment
- Removing or piling of finished products
- Packaging or moving piles or bundles

- Waiting for material handling equipment
- Waiting for instructions and clarification
- Counting and marking of products and administration
- Equipment or tooling problems
- Labor problems, lack of power, or compressed air
- Others

Rather than being satisfied with the 100 to 110% productivity based on the old method, the management took immediate action to minimize coil changeover, length changing and measuring methods, and other "nonproductive" times indicated as the highest nonproductive activities by the time studies. The improvements significantly increased the line utilization and productivity.

The nonproductive or "downtime" list shown in the above old study can be replaced with new studies using actual times for existing lines. Because the roll forming line generates income only when it is running, it is imperative to reduce the downtimes.

14.3 Improving Productivity

The steps to improve productivity (line utilization) are endless and their cost ranges between practically zero to very high.

14.3.1 Low Cost Improvements

Among the low cost improvements are:

- Improved production scheduling — for example, placing one type of material on the line only once a day.
- Better inventory control — running out of material too frequently reduces efficiency but "never running out" requires so much extra inventory, that a company cannot afford to carry it.
- Improve product design — for example, changing from "nonnesting" profile to nesting one, the roll forming speed can be increased by 40 to 75%.
- Eliminate the waiting time for coils — always store a few extra coils in the area around the uncoiler.
- Minimize the time spent on administrative assignments.

To meet with the accounting requirements, it is not unusual that the operator (and coworkers) spend 1/2 an hour or more with administrative functions (filling out work orders, time cards, counting and marking products, and other functions etc.). If, in an 8-hr shift, the operator works 7.17 hr (assuming 30 min lunch and 2 × 10-min coffee breaks), then 1/2 an hour represents 7% of the working time or the cause of an additional 7% when the line is not working. Certain amount of administration is required, but reducing the time taken for this task will improve line efficiency.

- Order good tooling instead of mediocre ones; all tooling should be operator-friendly. It is strongly advisable to rather have two more passes over the minimum requirement than to have one less.
- Have good and updated setup charts available.
- Provide the necessary setup, equipment adjusting and packaging tooling for the work. All the required tooling, like wrenches, Allen keys, screwdrivers, strapping tools, measuring gages, and so on should be located at the line.
- Educate employees — all operators, supervisors, maintenance, and management personnel should have regular roll forming and safety education.

Given the importance of the above items, details on the above subjects are provided in separate chapters.

14.3.2 Medium and High Cost Improvements

Once the no cost/low cost improvements have been exhausted, it is time to consider the moderate/high cost efficiency improvements. They may include:

- Installing better coil handling equipment to minimize coil change times (such as double uncoiler and individual coil lifter). In sheet fed lines, it is important to reduce the sheet feeding/bundle replacement times and to consider using automatic sheet feeders.
- Improving finished product handling. Often, the line speed has to be reduced to match slower finished product handling/packaging. Mechanizing or automating material handling can speed up roll forming and even more significantly reduce the number of people working in the line. It is not unusual to have two, three, or four material handlers/packagers for one operator. The elimination of two, three, or four material handlers/packagers can reduce the labor content of the product by 40, 60, or 80%.
- Improving line adjustability to minimize wasted downtime and to improve quality.
- Considering replacing the press(es) if the maximum line speed is restricted by the slow punching or cutting press(es).
- Increasing the line speed (one of the last medium cost resources).
- Purchasing new and more efficient line.

There are countless other ways to contribute to productivity improvement and thus reducing product cost. Each individual case has to be separately assessed but there are hardly any production lines, which efficiency (utilization) cannot be increased by 10, 20, 30, or sometimes over 50%.

14.4 Case Studies

14.4.1 General Information about Case Studies

- All case studies are based on real life examples but using fictitious data.
- In the "case studies," imperial units (inch, feet, pound, etc.) and dollar ($) values are used. They can be easily substituted with metric units and other currencies.
- Labor rates, material costs, equipment, and tooling costs are fictional and are used as examples only. Actual costs should be substituted in the equations.
- In the case studies the available production time (hours, minutes) per shift or per year are based on the following figures:

	365	Days in the year
	− 104	Days of Saturdays and Sundays
	− 10	Days of statutory holidays
	− 14	Days of maintenance or other reasons the line is not operating
Total	**237**	Days in the year are available for production
	8.000	Hour shift
	− 0.833	Hour breaks (30 min lunch, 2 × 10 min coffee breaks)
	7.166	Hour shift × 60 min = 430 working minutes per 8-hr shift

or 237 × 430 = 101,910 working minutes per year per shift, or rounded up **102,000 min per year per shift**.

Naturally, working overtime, weekends, and holidays as well as working in two or two shifts will increase the available working minutes per year.

- The 30 to 40% line utilization used in the examples is based on the average of the actual results in many roll forming plants. The figures can be substituted with actual figures based on local observations and calculations, but it is suggested not to apply overly optimistic high utilization figures.

- If, in the example, the line utilization factor is, say, 0.33, then the line is running only at 102,000 × 0.33 = 33,660 min/year.
- Continuing the above example, the total length produced in a year by a mill running at 120 ft/min will be 120 × 33,660 = 4,039,200 ft/year (over 4 million ft).

  The production per shift for a mill running at 120 ft/min and at 33% line utilization will be 430 min/shift × 120 ft/min × 0.33 = 17,028 ft/shift.
- If the product is 3-ft long (36 min), then the shift output will be 17,028 ÷ 3 = 5676 pc and the yearly output will be 4,039,200 ÷ 3 = 1,346,400 pc.

Warning: To calculate the line utilization, the maximum feasible process speed should be used. If an in-line process, such as welding or packaging, significantly reduces the actual speed the utilization percentage will be misleadingly high because of the few coil changes in a shift (see also Section 14.4.7). In such cases, for example, installing an additional welding or packaging unit and running the mill twice as fast, the output can be doubled.

14.4.2 Case Study "A" — Hat Section

Company "A" plans to purchase a single-purpose roll forming line to produce "hat" sections (1-in. high, 1-in. center width, 1-in. wings).

The required lengths are 18, 36, and 54 in. in about equal quantities.

Based on the previously calculation, 102,000 min per year per shift per equipment production time is available. Past experience indicate that this type of single purpose line utilization can be 38%. Therefore, the actual production time will be:

$$102{,}000 \times 0.38 = 38{,}760 \text{ min/year}$$

The production quantities will depend on the line speed and product lengths. For the first approach, consider three different line speeds (50, 100, or 200 ft/min). To cut the three different length of parts (1.5, 3, and 4.5 ft), the following number of cuts per minute are required:

	Required Number of Cuts (Strokes per Minute)		
At Line Speed (ft/min)	1.5 ft (18 min)	3 ft (36 min)	4.5 ft (54 min)
50	*33*	16.7	11.1
100	66.7	*33.3*	*22.2*
200	133.3	66.7	44.4

If a mechanical press with 40 strokes per minute is purchased, then the maximum forming speed is limited to 40 times the product length or, in other words:

the 18-in. (1.5-ft) pieces can be roll formed at a maximum 60 ft/min speed
36-in. (3-ft) pieces can be roll formed at a maximum 120 ft/min speed
and 54-in. (4.5-ft) pieces can be roll formed at a maximum 180 ft/min speed

The production quantities have to be recalculated with these speeds:

$$\frac{60}{1.5} = \frac{120}{3} = \frac{180}{4.5} = 40 \text{ pc/min (for any of \textit{these} three lengths)}$$

Available time per year is 38,760 min.

The yearly total output will be 38,760 × 40 = 1,550,400 pc/year:

or 516,800 pc of 1.5-ft long part
516,800 pc of 3.0-ft long part, and
516,800 pc of 4.5-ft long part if equal quantities are required.

If more parts are required, then a press with a higher stroke per minute is required. For example, utilizing a 60 stroke per minute press, the output can be 50% higher assuming that the line can run faster. However, the maximum line speed may be restricted by the length tolerance. This means not only a different press, but different die accelerator and possibly different length measuring system will be required. The maximum number of pieces per minute can be also constrained by the handling/bundling/packaging capacity at the end of the line.

Alternative solutions to produce more parts can be for example operating the same line in more than one shift or running two products side by side at the same time. For the latter and more economical solution, a double capacity uncoiler, a different and a twice as wide mill and a double capacity press would be required.

If the hat section has prepunched hole(s), then the technological aspects of this case study must be extended.

One hole close to the end may be punched with the punch incorporated into the single shear cutoff die.

If there is one hole at each end of the product, then the punches might be incorporated into a double shear cutoff die, but this press must have a capacity twice as high as that of the single shear press. One, two, or a larger number of holes can be prepunched in a separate press, or in certain cases they can be rotary punched.

14.4.3 Case Study “B” — Shelving

Company “B” decides to roll form metal shelving and has to choose one of the two recommended production technologies (Line B1 or Line B2). The shelf lengths are 24 in. (2 ft), 36 in. (3 ft), and 48 in. (4 ft).

Line B1	Line B2
Starts from coil	Starts from coil
Blanks four corners	Blanks four corners and cuts to length
Roll forms two longitudinal edges	Roll forms longitudinal edges
Cuts to length and bends short ends	Bends short ends

Line B1 is a continuous line producing shelves with single end bends (Figure 4.51). Shelves are separated in the last operation. If a mechanical press is used, then the maximum speed of the line is restricted by the 40 stroke per minute press.

$$\begin{aligned}\text{Maximum line speed } & 2\text{ ft} \times 40 = 80\text{ ft/min}\\ & 3\text{ ft} \times 40 = 120\text{ ft/min}\\ & 4\text{ ft} \times 40 = 160\text{ ft/min}\end{aligned}$$

With this method, theoretically, 40 shelves can be manufactured per minute while the mill is running. Using a 35% line utilization factor, the output would be

$$40 \times 60 \times 7.166 \times 0.35 = 6{,}019 \text{ shelves per 8-hr shift.}$$

However, 40 shelves per minute means that one shelf is produced every 1.5 sec. Removing the shelf from the line, possibly flipping (turning over) every second one, nesting and bundling the finished products will be a major challenge and most probably a lower line speed must be used. A more reasonable output figure is 8 to 10 shelves per minute.

Line B2 is also a continuous line but the shelf blanks are separated in the second operation, after corner notching.

The line speed is restricted by the end (wing) bender. The maximum speed can be 8 sec/cycle. After the blank with the roll formed longitudinal edge enters the wing bender, it has to be located and stopped, two ends clamped, short ends bent, clamps and benders released, and shelf has to be driven out from the winger bender.

$$8\text{ sec/shelf} = 7.5\text{ pc/min speed}$$

The estimated shift output, using 40% line utilization (slower speed, less coil changes) is

$7.5 \times 430 \times 0.40 = 1290$ shelves per shift.

The line speed will be $7.5 \times 2 = 15$ ft/min for the 2-ft long shelves, 22.5 ft/min for the 3-ft long shelves, and 30 ft/min for the 4-ft long shelves.

Additional considerations to reduce changeover time (increase utilization) can be

- For variable widths, use duplex line
- For widths and length changes, use PLC/computer control and servo motors
- Use computer control for the complete line, including packaging.

If the short end requires a double bend, then the line speed for both Line B1 and Line B2 will be 7.5 shelves per minute.

It is feasible to double the line output to 15 shelves per minute by splitting the line after roll forming and having two end-bending lines attached to it.

The corner notching operation can be combined with punching holes into the shelves at the entry side of the line.

There are several more alternative ways to produce shelves. This case study emphasizes the importance of selecting the most suitable roll forming line. The chosen technology, method, equipment, and tooling predetermine the cost and quality of the products, as well as the profitability of the operation.

14.4.4 Case Study "C" — Studs

What are the estimated yearly outputs of an older, traditional stud mill and a special, short changeover stud mill?

For the sake of simplicity, this case study is based on roll forming 8-ft. long studs with punched holes at every 2 ft, with the first hole always at a fixed distance from one end of the stud.

14.4.4.1 Traditional Line C1

Line speed is 160 ft/min, the required cutoff press cycle is 20 strokes per minute.
Holes at every 2 ft, the prepunch press cycle must be at a minimum of 80 strokes per minute.
Shift output: 160 ft/min × 430 min/shift × 0.36 = 24,768 ft/shift or approximately 3096 pc/shift.
Yearly production: $160 \times 102{,}000 \times 0.36 = 5{,}875{,}200$ ft/y or 734,400 pc/y.

14.4.4.2 Specialized Stud Line C2

Line speed 350 ft/min, the cutoff press cycle is close to 44 strokes per minute.
Holes punched at every 2 ft, the prepunch press cycle must be over 175 strokes per minute if single holes are punched. Line utilization is assumed as 30% (more coil changes).
Shift output: $350 \times 430 \times 0.3 = 45{,}150$ ft/shift or 5644 pc/shift.
Yearly production: $350 \times 102{,}000 \times 0.3 = 10{,}710{,}000$ ft/year or 1,338,750 pc/year (8-ft long).

The output of Line C1 is 20 pc/min or one stud in every 3 sec. One person can turn over every second stud and bundle them in packages of 10 pieces. Another person prepares the "shipping bundles" from these 10 packs.

The output of Line C2 is 44 pc/min or one stud in every 1.36 sec. Automated high speed packaging for both the "10 packs" and "shipping bundles" is recommended.

The output of the specialized line is 2.2 times higher than that of the traditional line and it requires one operator only instead of three. This means that the labor content of the traditional line is 6.6 times higher than that of the specialized line. Because the material content is already reduced to the minimum, saving in the labor cost is an important consideration. On the other hand, the specialized lines are considerably more expensive.

Additional important concern is the changeover time from one profile to the next one.

Typical Changeover Times in Minutes

		Web	Leg
Traditional (old) mill	Standard spacers	180	240
	Split spacers	30	240
Duplex mill		3	200
Specialized mill		3	3

14.4.5 Case Study "D" — Guard Rail

Company "D" is considering the installation of a new special-purpose roll forming line to produce "W" guard rails. The required quantity is about 390,000 pc/year in one shift operation.

Let's assume that all guard rails are 12 to 6-in. long and have the standard hole pattern at both ends and at the center.

Company "D" requested quotations for a guard rail line from different suppliers. Suppliers suggested four different technologies to fabricate the same product, all starting from coil.

(a) Cut-to-length — transfer (longitudinally or across)
Punch holes — transfer (longitudinally or across)
Roll form
  Punching can be completed
  - All in one hit in a long press
  - One larger press to punch the end holes in one group and a smaller press punching the center holes at the same time
  - One press punching the two groups of end holes and after 5-ft feed, the center holes (using gagged punches).

(b) Punch the holes (in one of the three different ways as described above)
Cut-to-length
Roll Form

(c) Punching holes and cut-to-length in one die (or 2 separate dies operated at the same time)
Roll Form

(d) Punch the holes (in one of the different ways as described above)
Roll Form
Cut to length after roll forming

After a lengthy evaluation process, the company decided to adopt the following technology:

- Starting coil size will be 20 tons
- Pull the coil from the uncoiler by a flattener into a loop
- A rotary feeder will feed the coil into the two presses located one after the other. The first press punches the center holes, the second one punches the two adjacent group of end holes
- From the presses, the prepunched strip enters into a loop
- From the loop, the strip enters the roll former
- The guard rails, gaged from the end holes, will be cut to length at the end of the mill and will be automatically stacked.

The technology of cutting to length after roll forming was selected because it was anticipated that the continuously roll formed product will have less end flare than the guard rails roll formed from precut blanks.

Punching all holes at the same time offers the best hole location tolerances. If the complete punching and coil feed cycle is 6 sec, then the output is 10 pieces per minute (125 ft/min production speed).

At that speed and 0.100-in. material thickness, it will take about 12 min to run one 10-t coil (or 18 min for 15-t coil and 24 min for 24-t coil). The coil change and the strapping and removal of the stacked bundles take time. If the stacked bundles can be removed efficiently, then using larger coils can increase the line utilization. Assuming a 38% line utilization, the shift output would be

$125 \times 60 \times 7.166 \times 0.38 = 20{,}425$ ft or approximately 1633 pc/shift or
1633 pc/shift × 237 shifts/year = 387,021 guardrails/year in one shift operation.

This output can greatly vary, depending on the coil weight, efficiency of coil loading, method of finished product removal, quality of the equipment and tooling, know-how and attitude of the operators, time spent on quality control, administration, and others.

The technology to be selected depends on the suppliers' know-how and experience, price, and the expertise of company "D". Depending on several factors, possibly flying prepunching dies will be used in lieu of the coil feeding. Using flying dies, the speed of roll forming may be increased but the permissible rail length tolerance must be checked. Tight hole-to-hole tolerance can be kept if the three groups of punches hit the guard rail at the same time. However, regardless which approach is selected, sufficient number of roll forming passes and good tooling will always be an important factor.

14.4.6 Case Study "E" — Siding and Roofing

Company "E" initiated a cost reduction study. They concentrated on the labor content of the product (output), based on the assumption that there is no room for saving material because the profile (blank width) and thickness is predetermined. However, they found out that the old length-measuring system provides inaccurate length for the first piece cut after each stopping; therefore, the operators always start with a short piece that is thrown into the scrap bin. In addition to this waste, when they almost run out of the coil, the operator had to estimate where to cut the coil at the uncoiler so as to leave enough material to roll the last piece. After forming the last piece, the leftover ended up in the scrap bin too.

Changing to an updated length measuring system, the first short piece and the last "leftover" piece scrap can almost entirely be eliminated.

The mill producing the sidings was subplated (rafted) and run at 190 ft/min speed.

To provide a short delivery cycle, the operator changed profiles in an average three times per shift. The profile change took 40 min (0.66 hr). Because of the high speed and frequent color and thickness (coil) change, the line utilization was at the best 30% for each profile.

Production time: $7.17 - (3 \times 0.66) = 5.20$ hr = 311 min/shift
Production output: $310 \times 190 \times 0.3 = 17{,}727$ ft/shift.

If the profile would have been changed only once per shift, then the output had been

$(7.17 - 0.66) \times 60 \times 0.30 \times 190 = 22{,}264$ ft/shift
or 26% higher than with three profile changes.

Fewer profile change would yield higher productivity and lower cost, but, in this case, providing customer satisfaction requires more frequent changes. The management of the company must establish the priorities and keep a precarious balance between production cost and "supplying on demand."

It is possible that a better productivity can be achieved with better scheduling and reducing the nonproductive times (increasing line utilization), while customers are still kept satisfied, but most probably causing an increase in the in-plant material handling cost.

14.4.7 Case Study "F" — Special Products

This company is roll forming prepainted, nonnestable products that were separated by paper (interleafed) during in-line packaging. Owing to the slow manual packaging, the line was running only at

50 ft/min speed. At that speed, only 2.2 coil changes were required per shift. The shift output was 17,200 ft. Because the line speed was reduced below the packaging speed, it was running practically without stopping. As a result, the line utilization was about 80%.

Caution: Calculating the utilization of lines at slow speeds can be misleading. In this case, modifying the paint specification and changing the packaging technology would permit running the line three times the present speed or 150 ft/min. At 150 ft/min, the line capacity is 150 × 430 = 64,500.

Calculating with this speed, the actual utilization is 17,200/64,500 = 27%.

This calculation illustrates that calculating the utilization of a line at the (actual) slow speed can be misleading. For calculation, the fastest practical speed should be used.

If the changes are made and the line would run at 150 ft/min, then the six coil changes per shift would reduce the utilization to 75% and increases the anticipated output to 150 × 430 × 0.75 = 48,375 ft/shift from the original 17,200 ft/shift, a 2.8 times increase.

This case study reveals the importance of using the maximum possible roll forming speed when the line utilization is calculated. Using the maximum possible speed will make evident which other factors (punching, welding, packaging, etc.) are reducing the utilization.

14.5 Preliminary Tool and Equipment Cost Analysis

The calculations used in this section do not follow the traditional cost analysis or return on investment procedures; its main purpose is to provide the preliminary information with approximate tool and equipment cost per length unit or per piece that can be added to or compared with the material and labor cost. The examples reflect real-life situations, but the costs and labor rates are hypothetical ones. For current applications, these figures should be substituted with the actual equipment, tool costs, material costs, and actual labor rates (labor rates may include overhead).

14.6 Preliminary Cost Analysis

14.6.1 Base Prices

Assuming:

Equipment Cost $100,000
Tooling Cost $10,000
Labor Cost $20 per hour × 8 = $160 (16,000 ¢) per shift per operator.

14.6.1.1 Production Rate

Speed × utilization × hour work per shift × 60 min/hr
100 ft/min × 40% × 430 = 17,200 ft/shift (one operator)
Basic conversion (labor) cost: 16,000 ÷ 17,200 = $0.0093 (or 0.93 ¢ per ft).

14.6.1.2 Equipment Cost

A good-quality, well maintained, mill will last for 50 years; however, to be on the conservative side, for this case study, we use 20 years only:

20 years and assuming 2 shifts per day operation (400 shifts per year)
Line speed is 100 ft/min, utilization 40%
Shift production 100 × 430 × 0.4 = 17,200 ft
474 shifts per year × 17,200 ft/shift = 8,152,800 ft/year.

Assuming an equipment life of 20 years:

20 × 8.152 million ft = 163 million ft of products are produced in 20 years.

Basic equipment cost per feet length is:

100,000 ÷ 163,000,000 = $0.0006 (or 0.06 ¢) per ft per $100,000 equipment cost.

If the equipment costs were $300,000, then the equipment cost per foot will be still less than 0.2 ¢ per ft

300,000 ÷ 163,000,000 = 0.18 ¢ per ft

14.6.1.3 Tooling Cost

Total 3,000,000 ft is produced with one set of tooling.

Basic tooling cost per foot is:

$10,000 ÷ 3,000,000 = $0.0033 (or 0.33 ¢ per ft per $10,000) tooling cost.

14.6.1.4 Example (Narrow Section)

Equipment $400,000 one operator
Tooling $50,000
1 million ft (total requirement from this profile)
Labor cost 0.93 ¢ per ft
Equipment cost 0.24 ¢ per ft (0.06 × 4)
Tooling cost 1.65 ¢ per ft (0.33 × 5)
Total of the above: 2.82 ¢ per ft.

If the total requirement is 3 million ft, and it can be produced with the same set of tooling, then:

Labor cost 0.93 ¢ per ft
Equipment cost 0.24 ¢ per ft
Tooling cost 0.55 ¢ per ft (1.65 ÷ 3 = 0.55)
Total of the above: 1.72 ¢ per ft.

The assumed material cost (depending on the cross-section and type of material) can be between 10 to 100 ¢ per ft. In this example, the tooling and equipment costs per foot are considerably less then the labor and material costs.

14.6.1.5 Example (Wide Panel)

180 ft/min

Equipment	$950,000	two operators
Tooling	$110,000	600,000 pcs @ 10 ft long = 6,000,000 ft

180 ft/min × 40% × 430 min/shift = 30,960 ft/shift
6,000,000 ÷ 30,960 = 194 shift to produce 6,000,000 ft
194 shift ÷ 237 shift/year = 0.82 year

Labor rate: 2 × $20 × 8 hr = $320 per shift (one shift operation)
Labor cost: $320 ÷ 30,960 = 1.34 ¢ per ft
Equipment cost: $950,000 ÷ 20 × 0.82 = $38,950 for this product (0.65 ¢/ft)
Tooling cost: $125,000 ÷ 6,000,000 = 2.08 ¢ per ft (based on this production run only)
Material cost: $1.50 per ft
Total: $1.54 per ft.

The above examples are not providing accurate figures but they can be used as guidelines for conservative preliminary calculations. The life of a good roll forming line is around 50 years. A life span of only 20 years was used in these examples, but maintenance and repair costs were not taken into consideration. Some of the tools may be used for producing over 10 million ft of products, others much less.

A labor rate of $20 was used in the examples. This rate can easily be substituted with the actual rates, which including overheads, may go as high as $150 per hour. At several companies, the equipment cost is included in the overhead cost. The end result will also be influenced by the accounting method used by the company.

Consequently, it underlines the recommendation of not trying to save money on equipment and tooling, not forcing the supplier to cut price, quality or number of passes, and not making tool and equipment purchase decisions based on cost alone.

15

Unusual, New, and Future Roll Forming Technologies

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George T. Halmos
Delta Engineering Inc.

15.1 The Last 100 Years

The first roll forming mills appeared around 1900, and the application of roll forming spread slowly in the first half of the twentieth century.

Roll forming became more popular after World War Two when the demand for formed metal parts increased. Owing to the high productivity of roll forming lines, and the increasing labor cost, gradually more and more products designed for brake forming were roll formed. Although the basic structures of the today's roll forming mills are not much different than those used in the early years, new improvements were introduced to extend the capacity of roll forming and to increase its efficiency.

15.2 The Future of Roll Forming

It is not easy to predict the direction in which the roll forming industry will progress, driven by the fast changing technology, growing global competition, and tougher requirements.

Roll forming equipment and tooling manufacturers and the users proved many times in the past that under pressure they can achieve the "impossible." It is true that the impossible takes more time and may cost more, but there are many products, considered "impossible to manufacture" 10 to 15 years ago, that are being roll formed now. What are the impossible products today that the industry will roll form in the near future?

Although the future of roll forming cannot be foreseen, it can be predicted with certainty that to be successful in the manufacturing environment, the plants will always need:

- Enhanced product design
- Improved material
- Better and more efficient equipment
- Improved tooling and
- Better educated and motivated workforce

15.2.1 Enhanced Designs and Product Standards

Product designs will be more orientated towards roll forming technology, and they will be more complex as roll forming technology develops.

A significant percentage of the accepted and current product standards are based on half a century old (or even older) industrial standards and practices. Some of these standards, created with the best intention to ensure quality and uniformity, can retard development, prevent innovations, and affect the supply of adequate quality but lower-priced products.

The trend will be to update many of these standards, based on performance specifications rather than dimensions and other descriptions.

15.2.2 Materials

The thickness limits of the presently roll formed materials will extend from less than 0.002 to 1–2 in. (0.05 to 50 mm) and above.

The trend of using thinner but higher strength material, as already practiced by the automotive and a few other industries, will be widespread. Material content can be reduced by 5 to 50% by using 30 to 600% higher yield strength material. In most cases, the benefit of the reduced product weight will far outstrip the increase in the material price per weight unit. The higher strength material will yield the same or even better quality products at lower prices.

Most of the coil and sheet tolerances established in the first half of the twentieth century will be tightened. The roll formed product manufacturers will not accept a ± 15% thickness tolerance of thinner steel coils, loose camber and flatness tolerances while they are pressured to manufacture products to very tight tolerances.

15.2.3 Equipment and Tooling

Roll forming equipment purchased today will operate well in the mid and second part of the twenty-first century. Therefore, progressive companies should look ahead into the future when procuring equipment, rather than applying the "good old" (40 to 50 years old), but outdated, technology.

Average roll forming lines are still running between 60 to 180 ft/min (20 to 60 m/min). To increase efficiency, many new roll forming lines will run at a speed of 600 to 800 ft/min (200 to 250 m/min) or faster.

The speed of the roll forming lines, in many cases, has been restricted by the number of strokes per minute of the mechanical, pneumatic, or hydraulic presses. The new compact hydraulic or other presses have the capacity of 150 to 200 strokes per minute.

Increased speed is not an impossible dream, lines have already been developed and are operated at 750 ft/min speed (230 m/min), cutting 7500 pieces per minute, in other words producing about half a million 1-in. (25-mm) long pieces per hour.

15.2.4 Flow of Material in the Mill

In the present systems, in almost all cases, the pass line is kept in a straight horizontal plane or it is inclined with a small increment from pass to pass. When forming a section, say, a "U" channel, the straight bend lines travel in the horizontal plane, and the edges not only move the same distance forward, but also move upwards at the same time. Hence, the edges travel a longer path than the straight bends as shown in Figure 15.1. If the stresses at the edges exceed the yield point, then the finished edges will remain permanently wavy.

It can be easily demonstrated that the "natural flow" is different. After forming the last 10 to 12 in. (about 250 to 300 mm) of a 60 to 70 in. (about 2-m) long metal strip to the finished shape, or bending a wallpaper of the same length to a 2 × 4 (Figure 15.2) and keeping the other end of the strip straight, the strip will take the shape of the "least resistance" or "lowest stress."

Viewing this model from the side (Figure 15.3a), it is obvious that the bottom part of the section does not travel in a straight plane. The edges of the wallpaper are not torn, which indicates that the above shape, following the "natural flow" (often called "downhill flow") has generated the least amount of stress and strain. In the presently used roll forming systems, the entry end is "forced down" to travel horizontally (see Figure 15.3b), thus creating stresses at the edges.

If the "natural flow" is better than the "horizontal flow," then why is this method not used? The main reason is that for the sake of cost, convenience, and habit, the mill drive shafts are positioned on the same level, especially in North America.

To follow the "natural flow" with all the drive shafts in one level, the mill would require larger

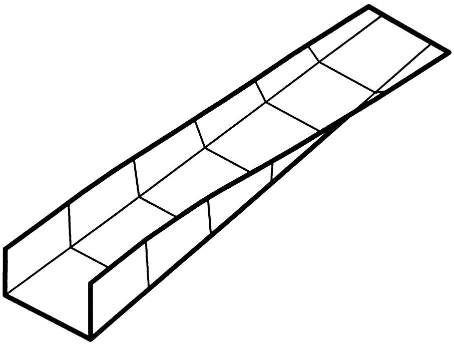


FIGURE 15.1 The edge of the "U" channel travels a longer path than the bent corner.

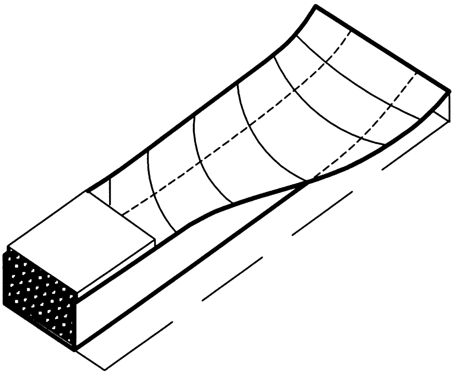
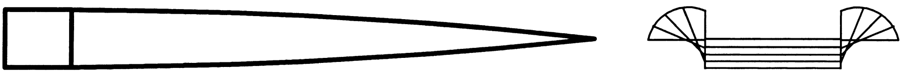
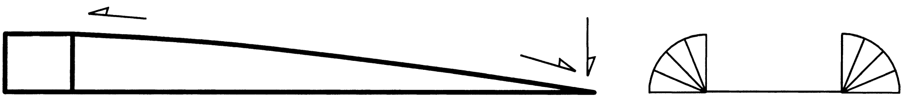


FIGURE 15.2 The stresses are minimized when the "natural flow" is followed.



NATURAL, MINIMUM STRESS FLOW OF MATERIAL
(a)



THE PRESENTLY APPLIED METHODS INDUCE HIGH STRESSES
(b)

FIGURE 15.3 "Natural flow" with downhill pass line (a) and same level pass line flow (b).

diameter rolls in the first passes (Figure 15.4). However, this is not practical; the larger diameter rolls would drive the material faster, thus creating buckles between passes.

The solution is to have roll forming mills with both the top and bottom shafts adjustable in height (Figure 15.5). This arrangement permits the use of the proper roll diameters. The shafts can be driven with universal joints, which are often used on rafted mills, or with individual, adjustable speed (or torque) motors. This approach is widely used in tube mills and in very few roll forming mills. (A certain amount of free flow is incorporated in the patented Cookson process, described by Albert Chu in the August 1969 issue of *Modern Metals*, pp. 65–66 and by Brian Evans in "Advanced Techniques and Machines for Cold Roll Forming", *Sheet Metal Industries*, July 1973, pp. 389–396 and August 1973, pp. 448–455).

If the "downhill flow," or the "flow of the least resistance," is followed, then the least amount of stress will be generated in the roll formed parts. Roll forming a shape with the least resistance will require fewer passes and less power, it will create less shaft deflection and yield better products at lower cost. Naturally, if this concept is accepted, most existing roll design methods have to be modified or discarded. Designers have to relearn how to establish the number of passes, how to specify the flow and how to design rolls. Of course, many of the existing computer-aided roll design programs will have to be modified too.

15.2.5 Position of the Shafts

Another "bad habit" of roll formers is the assumption that all the shafts must be horizontal and parallel. It is true that the shafts of the occasionally used side-rolls are not horizontal, but in most cases, the nondriven side-rolls are considered as "helpers" and not part of the main forming process.

There is no reason why the shafts could not be positioned in the optimum direction at any angle. The tube forming industry is already using considerably more "standard" vertical axis side-rolls than the roll forming industry.

Furthermore, if we are to use individual drives, then why not drive each nonhorizontal shaft? This arrangement will reduce roll wear and scuffing, and also will reduce the number of passes required to form the product. There were roll forming mills developed about 50 years ago with driven vertical shafts.

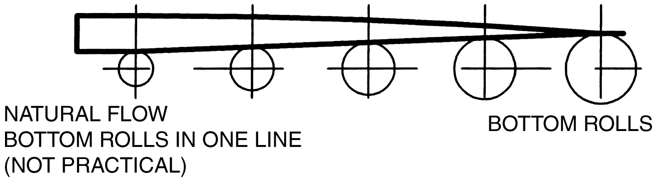


FIGURE 15.4 Downhill pass line forming with all bottom shafts in one level.

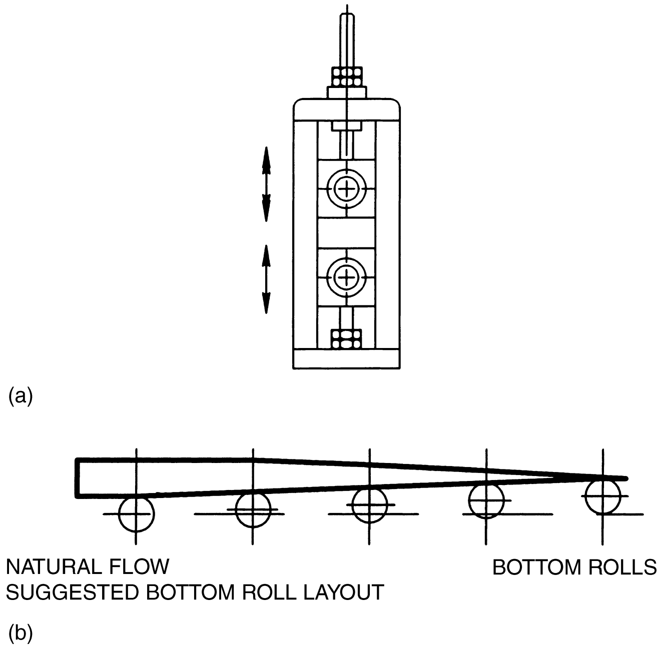


FIGURE 15.5 Adjustable bottom shafts (a) are required for proper “natural flow” forming (b).

15.2.6 Eliminating Shaft Bending

The most frequently damaged parts of the roll forming mills are bent shafts. Limited shaft deflections, well within the elastic limit, are anticipated, but unexpected deflection beyond the elastic limit creates permanent bends. Shafts can be permanently bent by incorrect setup, a significant increase in metal thickness, thick weld bead on the strip, objects dropped or left on the strip, and, most frequently, triple thickness of material entering between the rolls when the material buckles up between passes.

One method to avoid shaft damage or broken stands is to use “elastic” bearing block hold-down devices. Presently, most adjustable bearing blocks that are holding the ends of the shafts, are rigidly forced down by screws. However if these screws are replaced by hydraulic, pneumatic, or nitrogen cylinders, or by springs or other elastic methods, providing just sufficient pressure to form the section, then the top and bottom bearing blocks will part before the separating forces reach a level which will produce permanent shaft bending or other damages. The sudden increase in the bearing hold-down pressure or the movement of the bearing blocks can be sensed and the line stopped before additional damage occurs. Some of these ideas have been used for decades and some of them are patented.

15.3 Pull-Through Mills: Nondriven Rolls

In roll forming, it is assumed that the rotating, driven rolls move the material. However, there are several applications where the strip is “pulled” through a nondriven mill.

The visible, painted portion of the ceiling tile support “T” bars, the “V-shaped” section formed by Delta Engineering mentioned in Section 15.6.1, the small diameter tubular sections, as well as the corrugated lock-seamed tubes are formed in “pull-through” mills. These applications resemble the tension roll forming (Section 15.4) but without stressing the material above its yield point.

Even in the presently used driven mills, there are nondriven passes such as side-rolls, embossing rolls, and rotary piercing rolls.

Most probably, the trend will be to have more nondriven mill shafts than those used in the current mills.

15.4 Tension Roll Forming

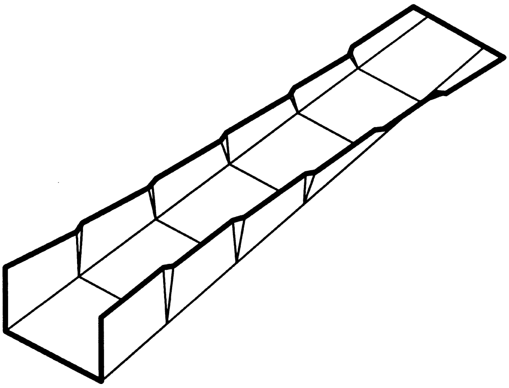


FIGURE 15.6 Frequently, most deformation occurs just ahead of the forming pass.

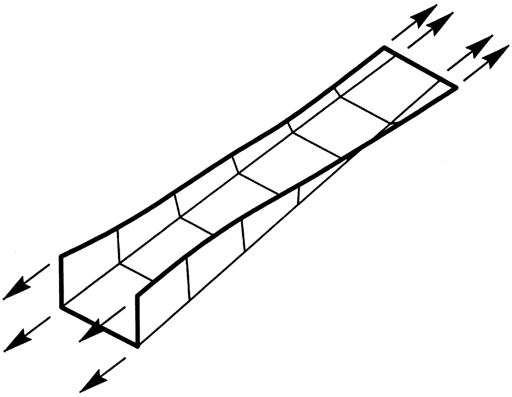


FIGURE 15.7 Sufficient tension can eliminate the extreme deformation ahead of the passes.

When a roll forming mill is stopped during roll forming, all of the top shafts are lifted up and the section from the first to the last pass is removed, then the section will reveal that a substantial percentage of the deformation occurs just ahead of the rolls (Figure 15.6). Assume that this section had been made of soft plastic and during roll forming, tension above the material's yield point is applied at both ends. It is easy to visualize that these local deformations will straighten out if the full length, from the starting strip to the finished shape is under tension (Figure 15.7). Applying tension just above the material's yield point is the central principle of tension roll forming [291, 432].

A practical approach to tension roll forming is to wind the starting strip through large diameter, urethane-coated rolls at the entry end and to pull the finished, formed section with caterpillar belts at the other end (Figure 15.8). The belts run at a speed somewhat faster than the entry strip, thus creating a stress above the yield point. The forces for small sections are relatively small. For example, for 0.030-in. thick and 2-in. wide steel with 30,000 psi yield (0.76 mm × 51 mm, 206 MPa yield), the force to stress the material above the yield point is about 1800 lb (810 kg). The energy requirement for tension roll forming can be minimized by converting the "torque required to brake" to the "torque needed to pull." This method is similar to the technology used in tension leveling.

In the case of tension roll forming, which generates a smooth flow between the flat strip and the finished section, theoretically, it would be possible to use the last forming pass only. In reality, this may not be achievable, but the number of passes can be reduced to half or less than what is needed for conventional roll forming. Tension roll forming will also yield straighter parts than conventional roll forming. The Baushinger effect may also reduce the forces and torque needed for forming. However, tension roll forming can only be applied to sections, which can be "grabbed" at the formed end, and it cannot be readily used for prepunched or prenotched parts.

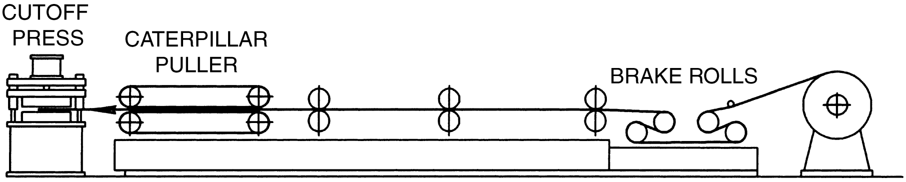


FIGURE 15.8 Caterpillar pulling belt and brake rolls can induce stresses above yield point in the strip.

Roll forming building panels with the above described "strip-holding" and "caterpillar-pulling" method will yield better quality products, free of center or edge waviness, as well as their forming will require fewer passes.

Tension roll forming has been used for many decades to produce continuously welded, powder-filled, tubular sections with single or multiple wires inside them. The finished product is wound on a large diameter drum that pulls the product through the rolls, replacing the caterpillar pulling device.

15.5 Combining Roll Forming and Cold Drawing

Utilizing the drum or caterpillar puller, a draw die can replace the last pass or some of the last passes. A solid or a rotary draw die will reduce the thickness of the material and will provide straight parts with tight dimensional tolerances. By utilizing the above principles, the author developed a mill in the 1980s.

15.6 Developing New Roll Forming Methods

One set of definition of roll forming is

- Bending of flat metal strips
- In continuous straight lines with multiple pairs of rotating, contoured rolls
- Without changing material thickness
- At room temperature

Several new ideas can be created by forgetting one's past experience, overcoming tunnel vision, and disregarding the existing rules and definitions. For example, why not roll form:

- Nonflat metal strip as a starting material
- In a noncontinuous line
- In a nonstraight line
- Not (only) with rolls
- Different thickness of the material
- Not at room temperature

Let us explore these possibilities in further detail.

15.6.1 Using Nonflat Starting Material

Most roll formers assume that the starting strip must be flat. However this is not a "must." For example, to reduce the tooling cost, Buffalo Specialty Products used standard, hot rolled, "U" channels as the starting material (*Precision Metal*, March 1989). This enabled them to form one bend line only instead of three, thus drastically reducing the tooling cost (Figure 15.9).

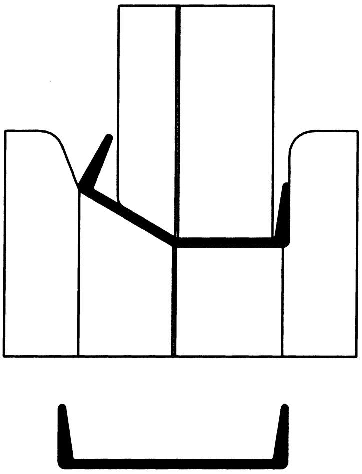


FIGURE 15.9 Using hot rolled "U" channel as starting material.

Another example is in order to utilize the leftover section of the wires used for other purpose, at the request of a customer, Delta Engineering made a piece of equipment to roll form this circle segment into a "V" shape, and then pull it through a draw die. In another process, these wires with a cross-section of "segments of a circle" were cold reduced to flat strips, slit longitudinally into two halves, corrugated and cut to length, all in one line. The forming speed was 700 ft/min. The length of the finished pieces was 1 in. To meet the above requirements, 140 cuts were made per second on both parallel exiting corrugated strips. The line produced about 16,800 pieces per minute or about one million pieces per hour.

15.6.2 Roll Forming Noncontinuous Bend Lines

According to the definition of roll forming, the flat metal strip is bent in continuous straight lines. Continuity is assumed because of the nature of roll forming. However, in some applications, it would be better to discontinue the ribs to leave space or a flat area for punching, embossing or other operations. Some manufacturer flattened back the embossed ribs at the end of transformer oil heat exchanger plates or similar products (Figure 15.10). However, a process to discontinue the stiffener ribs at certain point is better. In the April 1970 issue of *Sheet Metal Industries*, G.H. Pugh described a process developed by Joshua Bigwood where the shaft of the stiffener rib embossing rolls were lifted up by hydraulic cylinders to leave a specific part of the transformer plate flat. The shafts were pressed back again when embossing was continued.

A similar discontinuous rib forming process may be used when either the end of the products requires special forming or when only a certain part of the product, such as the bed of the pick-up truck (Figure 15.11) is roll formed.

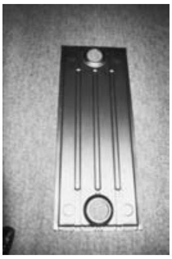


FIGURE 15.10 Roll formed ribs are "flattened" at the end of the transformer heat exchange panel.

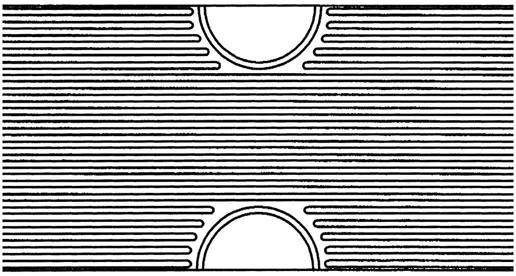


FIGURE 15.11 "Interrupted rib forming" can be used in pick-up truck beds.

15.6.3 Roll Forming Nonstraight Bend Lines

In almost all roll formed products, the bend lines are parallel. However, it is possible to form nonparallel lines by applying a special technique. A typical example of this technique is the roll formed, pie-shaped grain bin roof sheets (Figure 15.12).

With special equipment developed for another product, even the edges of curved dome-shaped silo roofs can be roll formed (Figure 15.13).

In the 1980s, B&K Machinery built a rotary embossing unit to form a snake-like embossment at the center of the standing seam panels shown in Figure 15.14 [315].

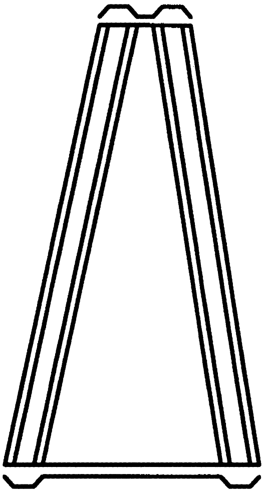


FIGURE 15.12 Nonparallel roll formed ribs.

A patent application has been filed to roll form wavy wall panels to produce panels with appearance substantially different from the straight roll formed wall panels. Two approaches are shown on Figure 15.15. These technologies have never been tried, and it is questionable whether they can be used when deeper sections are roll formed utilizing multiple passes. However, a few manufacturers recently disclosed that they occasionally produce products with wavy bend lines, although not intentionally.

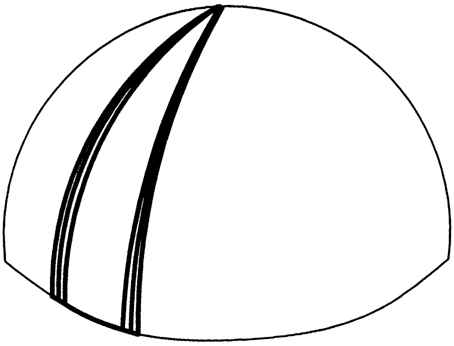


FIGURE 15.13 Roll formed dome section.

15.7 Roll Forming Tools

One of the cited definitions of roll forming is to form with "multiple pairs of rotating, contoured rolls." However, as with all the rules, there are exceptions:

Some roll forming "mills" have only a single pair of rolls.

Bronze shoes, plastic supports, flat cam rolls and other "tools" are frequently applied by the roll forming industry. The most frequently used other tools found around most roll forming mills are the 2 × 4s.

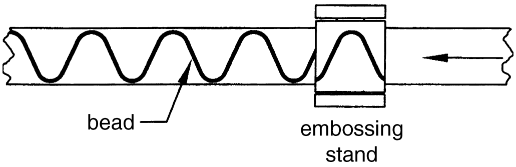


FIGURE 15.14 Rotary embossed sinus shaped bead.

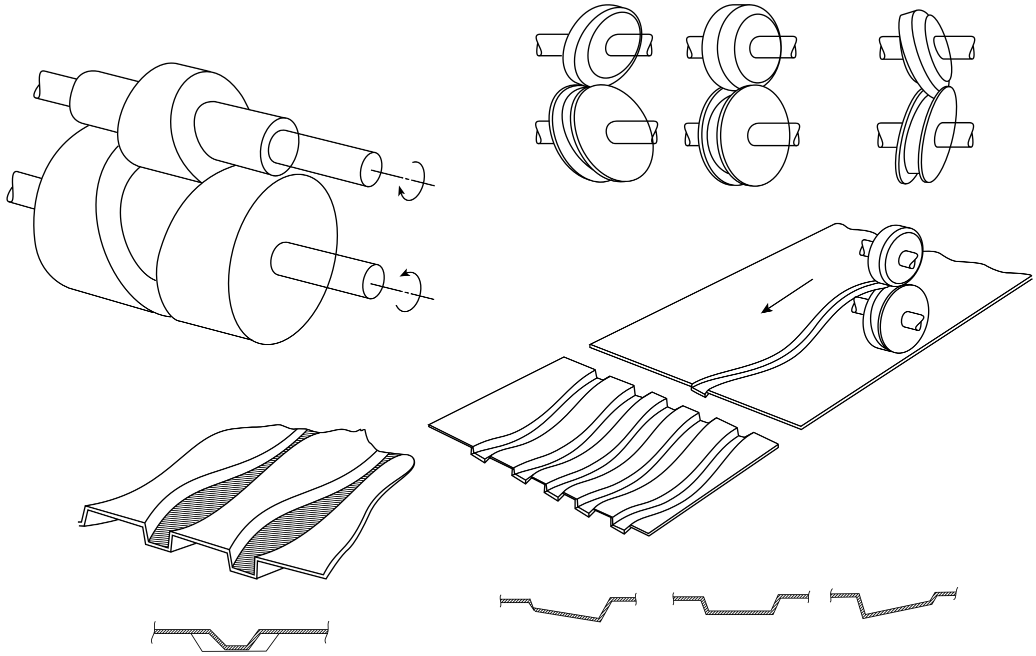


FIGURE 15.15 Roll forming wavy rib wall panel.

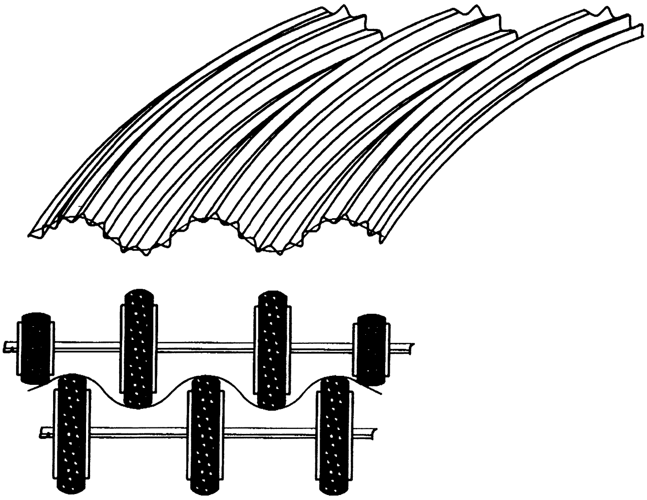


FIGURE 15.16 Preforming flat starting material to full section depth reduces the number of passes required for forming.

Urethane and other plastic rolls are occasionally incorporated in the forming process.

One manufacturer, by using a "homemade" roll former, managed to roll form deep corrugated sections in 6 passes instead of the traditional 22 to 24 passes. They "preformed" the cross-section to its full depth using a stand of nondriven car tires (Figure 15.16), allowing a very long entry section between the uncoiler and these car tire "rolls." This application shows the ingenuity of breaking with traditions, using roll material other than the tool steel and to some degree, the application of partial pull-through roll forming.

15.8 Reducing the Thickness of the Starting Material

Another definition of roll forming is to form without changing the thickness of the starting strip. However, the thickness is already reduced at the bend lines and occasionally some parts of the strip are thinned or as sometimes called "coined." In other cases, the edges of thicker sections are beveled by cold reduction to eliminate machining (Figure 15.17).

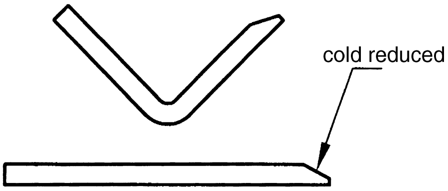


FIGURE 15.17 Cold reduction of the strip edge eliminates costly bevel machining.

Why not reduce thickness if it has advantages? Cold reduction passes are already installed in front of some mills to provide the starting strips with tight thickness tolerances across its full width. Cold reduction passes can also be installed at any pass, which must "coin" (cold roll) a part of the section to tight tolerance. A typical application is to keep tight tolerance on the "double thickness" sections of the drawer slides (Figure 15.18). A similar idea was described by Jacmorr Manufacturing Ltd. in the April 1990 issue of *Modern Metals*.

A word of caution is necessary however; the forces required to reduce thickness can be 10 to 100 times higher than the forces required for forming. Therefore, cold reduction should be carried out only with passes specifically designed for that purpose.

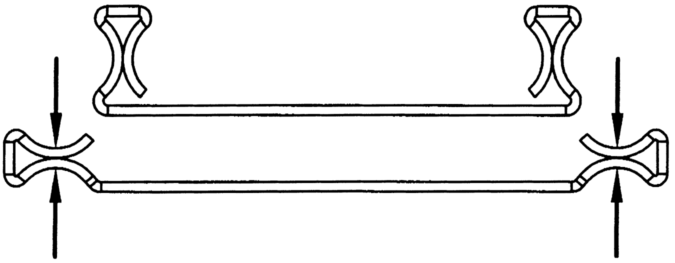


FIGURE 15.18 Cold reduction of drawer slide section provides tight tolerances at critical points.

A special roll former was built by Yoder to roll form a strip with variable thickness in late 1970s is now described by D.E. Beecher at the 1st International Conference on Rotary Metal-Working Processes in November 1979.

15.9 Forming at Elevated Temperature

The widely used expression "cold roll forming" is inaccurate. Roll forming can be implemented at a temperature higher than room temperature. For example, to avoid cracking of paints or laminates at sharp bend lines, the strip (or just the bend lines) can be preheated up to 130 to 230°F (55 to110°C) before entering into the forming rolls. The coating will be soft enough not to crack, but hard enough not to be stripped off the metal.

Hot roll forming of titanium at Boeing is described in the June 1971 issue of the *Metalworking Production*. The titanium strip was preheated to about 1470°F (800°C) and was passed through a special roll forming mill. In this case, titanium was roll formed at a high temperature because it could not be formed at room temperature. However, hot roll forming has lots of other advantages.

The forces required for cold reduction are very high. The yield point of the metal can be reduced drastically by increasing the temperature. At 1500°C, the yield strength of steel is about 1/5 to 1/10 of the yield strength at room temperature. This characteristic of metal was used by the smiths for thousands of years, and that is the reason why "I" beams, "U" channels, and other shapes, thick plates, and coils are still hot rolled today.

So, why not hot roll form sections? Is it simply because the sheet metal industry has a history and habit of working at room temperature?

The trend will be to install induction, high frequency, gas or other preheating methods in front of the roll forming mill to heat the full cross-section, or just the bend lines.

Roll forming metals at elevated temperature will require:

- Less passes (most probably)
- Less HP
- Smaller shaft diameters
- Smaller rolls (because of smaller shaft diameters)
- Shaft/roll cooling system

However, hot roll forming can doubtlessly extend the range of roll forming to and beyond 1 in. (25 mm).

There is also a chance that tension and hot roll forming can be combined to produce more economical products.

15.10 Hot Roll Forming Variable Cross-Sections

The cold reduction technology of strips described in Section 15.8 has been used for a long time but it requires high forces. Reducing selected parts of a strip is more feasible at high temperature. Figure 15.19

shows a typical example, whereby thinning the walls of a section, similarly to the webs of the "I" beams, more economical and lower priced products can be produced.

15.11 Hot Thickness Reduction along the Length of the Strip

Products are designed to withstand the maximum stresses or deflections. However, the stresses are usually not uniformly distributed along the length of the products. As a result, usually the uniform cross-sections are "overdesigned" all along the product lengths except at the maximum stress location.

Efforts have been made to optimize the weight of the products by changing their cross-section along their length to suit the varying stresses. Typical examples are the tapered light poles and changed column cross-sections from the bottom to the top of the buildings. Airplane manufacturers reduce the weight of the airplanes by etching out the unwanted thicknesses of materials at low stress areas. The automotive industry uses "custom tailored" blanks by welding together thicker and thinner sheets that will be formed into load bearing sections. In case of the roll formed section, the common way to reduce the weight of the uniform cross-section parts is to cut out material, for example, by punching holes.

Reducing the weight and cost of the product can be achieved easier by reducing the strip thickness at low stress areas. It is possible to reduce the strip thickness in a roll forming line built for this purpose by changing the gaps between the rolls in thickness reduction stands located ahead of the roll former (Figure 15.20). By varying the gaps with proper control, strips can be rolled with thickness varying in the longitudinal direction.

The variable thickness strip can then roll formed in the traditional way. A "U" channel roll formed with this technology is shown in Figure 15.21 but the process can be used for other cross-sections and having the thick–thin section variations at any desired locations.

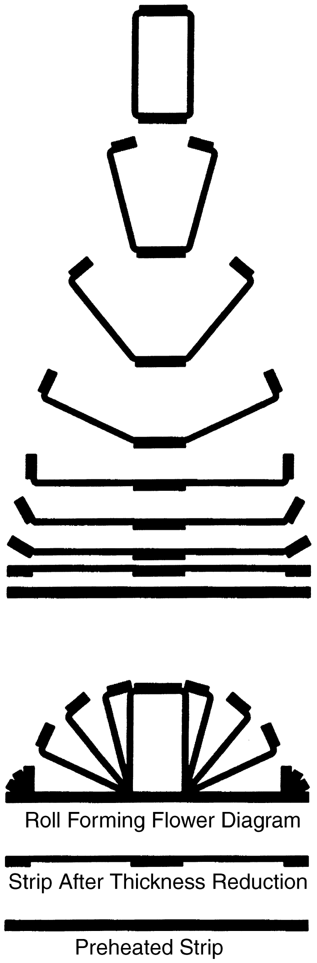


FIGURE 15.19 Reducing the strip thickness at specific segments of the strip provides more economical sections.

15.12 Welding Hot Roll Formed Sections

Sections that have already been preheated can be more readily finished as welded structures (Figure 15.22). Pressure welding of the hot flat parts of a section (Figure 15.23), or any other welding technology that is presently used, requires considerably less energy input than is needed for welding cold sections. The tendency for residual stresses, cracks, and distortion can be significantly reduced. Also, this

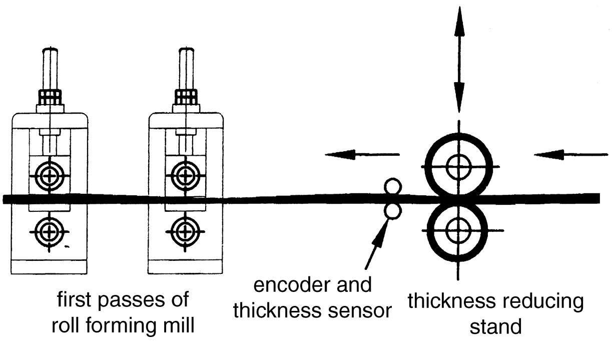

first passes of roll forming mill
encoder and thickness sensor
thickness reducing stand

FIGURE 15.20 Changing the thickness along the strip produces "custom-tailored" thicknesses for certain products.

method with controlled rate of cooling can be used to weld steels with high carbon content that prone to cracking.

The same hot rolling technology can be applied to make welded tubes.

15.13 Other "Hot" Processes

15.13.1 Hot Curving (Sweeping)

During curving, the outside fibers are under tension, the inside ones under compression. The minimum curving radius (maximum sweep number) for a product is limited by, among other factors, the shape of the section and the metal thickness. Products curved below a critical radius become distorted by the buckling of the compressed elements. Curving at high temperature allows more deformation at the compressed parts and longer elongation at the tensioned elements; as a result, the product can be curved to a smaller radius than those curved at room temperature.

Tubes are hot bent for a long time to a smaller radius than can be achieved at room temperature.

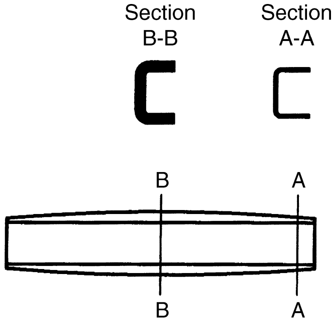


FIGURE 15.21 Custom-tailored roll formed "U" channel from strip with variable thicknesses.

15.14 In-Line Soldering, Brazing, and Heat Treating

The industry is already using some of the "in-line" heating processes. Thin wall lock-seamed tubes are brazed at the exit end by passing the tubes through an induction coil. Soldering and elevated temperature adhesive bonding can be achieved with the same technology.

Some metals, such as brass, stainless steel, zirconium, and nickel alloys, work harden at a very high rate. The above-mentioned in-line heating technology could be used for "flash" annealing of the partially or fully formed sections. The similar equipment can be used for in-line heat treating.

Presently, aluminum alloys, which can be "precipitations hardened" at room temperature, are processed in the following sequence; the coils are cross-corrugated for better air passage and are recoiled, they are heated to the required temperature, quenched in water, stored in refrigerators (to avoid hardening at room temperature before roll forming), and then roll formed after flattening out the cross-corrugations.

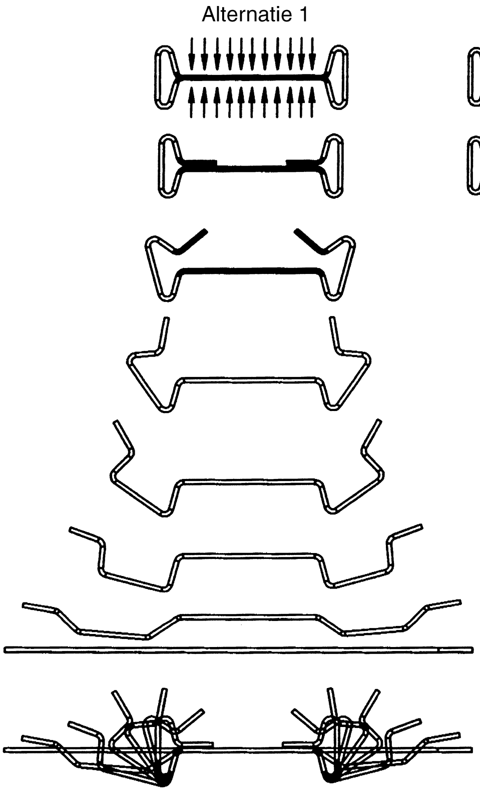


FIGURE 15.22 Roll formed, preheated, pressure welded cross-section.

This whole process can be simplified and be made less expensive by installing, just ahead of the mill, a short, high temperature flash heat-treating oven for the continuously running strips, followed by quenching the hot strip with water and roll forms it in an "all-in-one line process," producing the parts just in time (JIT).

The trend will be to use more hot roll forming and "in-line" heating of the strips or products for heat-treating, bonding, or other purposes.

15.15 Equipment and Tooling Requirements for Hot Roll Forming

For hot roll forming, additional equipment must be added to the line. Equipment for heating, possibly for forced cooling and sometimes pickling, is required. The type and capacity of the equipment will be influenced by the type of metal formed, the required maximum and lowest practical temperature, the heat capacity of the cross-section, and the forming speed.

15.15.1 Heating and Cooling Equipment

Depending on the requirements, heating can be completed before, during, or after roll forming. Conventional heating technology can be used. However, instead of soaking the coils for a long time in a furnace, the moving strip or formed section can be flash heated.

In some instances, the full cross-section must be heated, in others, only the bend lines or edges are preheated. High-speed edge heating, such as high-frequency or induction heating, can be used for forge welding of edges of closed sections.

Water cooling of the finished section may be required to quench the section after heat treatment, or when required for part handling. Additional equipment, such as a walking beam runout table to allow space for air cooling of the parts, may be needed at the exit end of the line.

15.15.2 Special Mill Design

Thin metals, about 0.050 in. (1.25 mm) or less, may be hot roll formed in conventional roll forming mills. However, thicker material may require special roll forming mills. These hot roll forming mills must have water-cooled shafts; heat-resistant rolls that are partially insulated from the shafts, special bearings, different lubricants for bearings, gears, and other components, water cooling and re-circulating system, heat-insulating cover, and often an exhaust system.

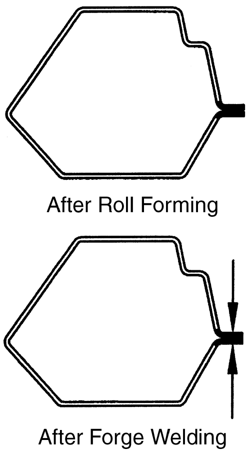


FIGURE 15.23 Roll formed, edge-heated, pressure welded tubular section.

If metal thickness reduction is substantial, then the forming speed changes caused by the thickness reduction from pass to pass have to be controlled differently from the conventional roll forming mills. The speed control of these mills will be similar to the ones used for sheet rolling at the mills (see also Section 15.15.4).

15.15.3 Other Equipment Requirements

If cutoff dies are used, then their cooling has to be considered. When heavy sections are roll formed, saw cutting typically is the most economical method to cut products to length. Roller conveyors, coolant recirculating pumps, and other components also are exposed to the heat.

15.15.4 Roll Design

The traditional roll design is based on the assumption that the thickness of the material does not change during roll forming.

The existing manual or computer-aided roll design method can be applied to hot roll forming if the thickness of the material is not changed, or if the thickness reduction is restricted to a small portion of the cross-section. However, because of the considerably lower strength and higher elongation at high temperatures, fewer passes will be required to obtain the finished shapes, especially when thick material is formed.

During roll forming, if a substantial part of the cross-section is reduced in thickness, then the flow of material will be different. In these cases, the roll design could be a hybrid between the traditional roll forming and the hot section rolling roll design. The substantial thickness reduction also will change the speed of the strip entering and exiting the thickness-reduction pass. The speed change necessitates changing the mill drive system.

15.15.5 Hot Roll Forming Conclusion

Hot roll forming often requires considerable additional space and capital investment for preheating the material and cooling the product, and different roll forming equipment may be needed. However, hot roll forming can provide the most economical manufacturing method for many products as well as extending the maximum thickness limit of forming to 2 in. (50 mm) or more.

The biggest obstacle in introducing hot roll forming is not the cost of the equipment, but rather the resistance of metal fabricators to change. Eventually, perhaps this resistance will be overcome as the benefits of the process are seen to outweigh the additional costs.

15.16 Press Tooling for Conventional Roll Forming Lines

Dramatic changes in prepunching or postpunching, notching, or cutoff dies are not expected. However, the already available compact high-speed hydraulic presses will allow operation at 600 to 800 ft/min (180 to 245 m/min) and faster. These small presses, along with technology borrowed from the turret punch system, will speed up tool change and the N/C or computer control will provide versatility.

15.17 Computer-Controlled Roll Forming Lines

The application of N/C, PLC, computers, and other devices will greatly increase in the near future. Some lines will operate according to the prepared programs, while others will be based on data received from sensors, and will adjust the mill, tooling, and other components to maintain uniform quality.

For example, in the case of a three-roll curving unit, a sensor can measure the curving radius during the curving process (Figure 15.24). The data feedback can be used to adjust the curving rolls to maintain the specified radius.

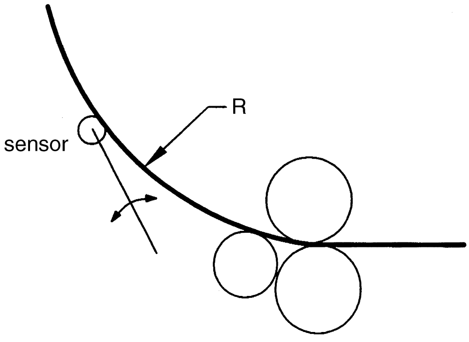


FIGURE 15.24 Sensor-controlled, servo motor adjusted curving unit.

Curving rolls, controlled by servo motor and governed by preprogrammed data, are already used to form parts with variable radii to tight tolerances (Figure 15.25). Some dimensions of the products, for example, the width of a "U" channel, can be held tightly by either measuring or sensing the width. The pass influencing the width can be adjusted either manually by push buttons or automatically through servo motors (see Figure 15.26).

When a roll forming mill with good tooling is properly set up, it can produce parts to very tight tolerances without any adjustment from consistent, uniform material. However, owing to fluctuation in strip dimensions, deviation from straightness and flatness, and variations in mechanical properties, the material is never uniform. Therefore, operators regularly have to make adjustments to the mill. Once enough data is available to know what mill adjustment has to be made when the finished product deviates from the specified shape, length, or straightness, a properly programmed computer can adjust the mill using servo motors. Servo motor adjusted shafts or side rollers can keep formed angles within tight tolerances.

Servo motor controlled straighteners have already been developed to keep products straight at the end of the line.

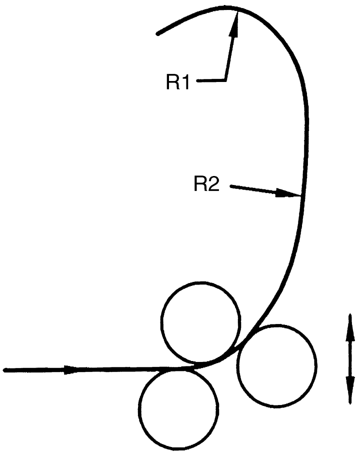


FIGURE 15.25 Computer-controlled curving unit can curve sections with different radii.

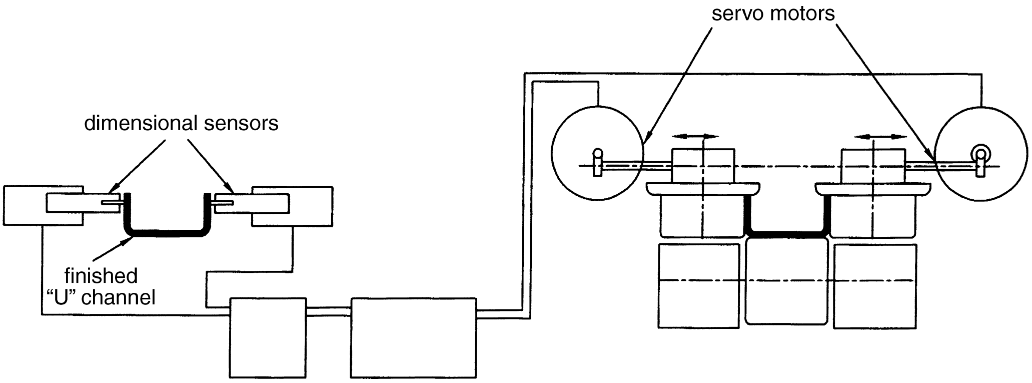


FIGURE 15.26 Tight dimensional tolerances can be held with servo motor adjusted rolls.

Computers or similar devices are used by many companies to control product lengths and quantities, fire presses, change punching pattern, control packaging, and to display troubles and maintenance schedules. Increasingly, the function of the operators will be taken over by computerized or automated devices. It will also make operating several lines by one operator possible; a practice already used by a few advanced companies. Whether the line is simple or highly sophisticated, skillful, motivated, and highly educated operators will always be needed.

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Appendices

Appendix 1: Conversion Units and Factors R7 FS (Jan 16, 2005) A-1
Length • Area • Volume (Capacity) • Mass (Weight) • Pressure or Stress • Velocity • Temperature • Energy (Work), Force, and Heat
Appendix 2 .... A-3
Length Conversion Tables: in. to mm and mm to in. • Thickness conversion table (fraction, inch, millimeter, steel weight lb/sqft and kg/m^2) • Pressure or Stress Conversion Table psi to MPa (1000 psi = 6.894757 MPa) • Pressure or Stress Conversion Table MPa to ksi (1 MPa = 0.1450377 ksi) • Temperature Conversion Table

Appendix 1: Conversion Units and Factors R7 FS (Jan 16, 2005)

Data listed under this heading maybe used as a guide for conversion between the U.S. conventional, U.K., and Canadian Imperial units and metric units plus occasionally SI (international system of units) of measurements. Wherever it is applicable, the units are rounded-off to digits practical in the roll forming industry.

Units not used by the industry, for example karat, mile, acre, cm, deciliter, km, and so on, are not listed in these tables.

Symbols are based on SI units but often comply with former units widely used by the industry. Units are abbreviated in one or more ways.

inch	in.
foot	ft
pound	lb
square inch	sqin or in.^{2} or psi
square foot	sqft or ft^2
pound per square inch	lb/sqin
cubic inch	cu in. or in.^{3}
cubic foot	cuft or ft^3
1000 pound per square inch	psi
N	Newton
Pa	Pascal
pound per square foot	lb/sqft or lb/ft
f	force
W	Watt
BTU	British Thermal Unit

1.1 Length

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
1 ft = 12 in.	1 in. = 25.4 mm	1 m = 1000 mm	1 mm = .03937 in.
	1 ft = 304.8 mm		1 mm = 0.0032808 ft
	1 ft = 0.3048 m		1 m = 39.37 in.
			1 m = 3.28084 ft

(For details and thickness conversion, see Appendix 2.1 and Appendix 2.2).

1.2 Area

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
	1 in^2 = 645.16 mm^2	1 m^2 = 1,000,000 mm^2	1 mm^2 = 0.00155 in.^{2}
1 ft^2 = 144 in.^{2}	1 sqft = 0.0929 m^2		1 m^2 = 10.7639 ft^2
			1 m^2 = 1550 in.^{2}

1.3 Volume (Capacity)

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
1 ft^3 = 1728 in.^{3}	1 in.^{3} = 16,387.064 mm^3	1 m^3 = 1×10^9 mm^3	1 mm^3 = 0.00006102 in.^{3}
1 U.S. gal = 231 in.^{3}	1 in.^{3} = 0.016387 l	1 m^3 = 1000 l	1 m^3 = 61,023.744 in.^{3}
1 U.S. gal = 0.1337 ft^3	1 ft^3 = 0.0283168 m^3	1 l = 1×10^6 mm^3	1 m^3 = 35.3147 ft^3
1 U.S. gal = 0.833 Imp gal	1 U.S. gal = 3.78541 l		1 m^3 = 264.172 U.S. gal
1 Imp gal = 277.42 in.^{3}	1 imp gal = 4.54609 l		1 m^3 = 219.969 Imp gal
1 Imp gal = 0.1606 ft^3			1 l = 61.02374 in.^{3}
1 Imp gal = 1.201 U.S. gal			1 l = 0.0353146 ft^3
			1 l = 0.26417 U.S. gal
			1 l = 0.21997 imp gal

1.4 Mass (Weight)

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
lb pound	1 lb = 0.453592 kg	kg kilogram = 1000 g	1 kg = 2.204624 lb
1 ton = 2000 lb	1 lb/sqft = 4.4882424 kg/m	1 ton = 1000 kg	1 ton = 2205 lb
			1 kg/m = 0.204816 lb/sqft

1.5 Pressure or Stress

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
psi pound per square inch	1 lbf/in. = 6.894757 kPa	MPa Mega Pascal	1 MPa = 0.1450377 ksi
	1000 psi = 6.894757 MPa	1 kPa (kN/m) = 1 kilo Pascal	1 N = 4.44822 lbft
	1 lbf = 4.448,221,615,260 5N	1 MPa = 1000 kPa	
		1 kgf/m = 9.807 kPa	

(For details, see Appendix 2.3 and Appendix 2.4).

1.6 Velocity

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
ft/min feet per minute	1 ft/min = 0.3048 m/min	m/min meter/minute	1 m/min = 3.28084 ft/min
in./sec inch per second	1 in./sec = 25.4 mm/sec	mm/sec millimeter/second	1 mm/sec = 0.03937 in./sec

1.7 Temperature

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
F degree Fahrenheit	$\Lambda c = (9/5 \times F_{degree}) + 32$	C degree Celsius	$\Lambda f = (C_{degree} - 32) \times 5/9$

(For details, see Appendix 2.5).

1.8 Energy (Work), Force, and Heat

Imperial units	Imperial to Metric	Metric units	Metric to Imperial
ft. lbf foot-pound force	1 ft. lbf = 1.355818 J	J joule	1 J = 0.7376 ft. lbf
lbf pound-force	1 lbf = 0.0044482 kN	kN kilo Newton	1 kN = 224.81 lbf
hp horsepower	1 lbf = 0.453592 kgf	W watt	1 kgf = 2.2046 lbf
	1 hp = 745.699 W	kW kilowatt	
	1 hp = 0.745699 kW	1 hp h = 0.7457 kWh	
	1BTU = 0.293 Wh		

Appendix 2

2.1 Length Conversion Tables: in. to mm and mm to in.

in. to mm	0.001	0.01	0.1	1	10	100	in.
1	0.0254	0.254	2.54	25.4	254	2540	
2	0.0508	0.508	5.08	50.8	508	5080	
3	0.0762	0.762	7.62	76.2	762	7620	
4	0.1016	1.016	10.16	101.6	1016	10160	
5	0.127	1.27	12.7	127	1270	12700	
6	0.1524	1.524	15.24	152.4	1524	15240	
7	0.1778	1.778	17.78	177.8	1778	17780	
8	0.2032	2.032	20.32	203.2	2032	20320	
9	0.2286	2.286	22.86	228.6	2286	22860	
10	0.254	2.54	25.4	254	2540	25400	

mm to in.	0.01	0.1	1	10	100	1000	mm
1	0.0004	0.004	0.039	0.394	3.937	39.370	
2	0.0008	0.008	0.079	0.787	7.874	78.740	
3	0.0012	0.012	0.118	1.181	11.811	118.110	
4	0.0016	0.016	0.157	1.575	15.748	157.480	
5	0.0020	0.020	0.197	1.969	19.685	196.850	
6	0.0024	0.024	0.236	2.362	23.622	236.220	
7	0.0028	0.028	0.276	2.756	27.559	275.591	
8	0.0031	0.031	0.315	3.150	31.496	314.961	
9	0.0035	0.035	0.354	3.543	35.433	354.331	
10	0.0039	0.039	0.394	3.937	39.370	393.701	

Examples for in. to mm: 0.2 mm 0.2 in. = 5.08 mm, 80 in. = 2032 mm. Examples for mm. to in.: 0.2 mm = 0.008 in., 5000 mm = 196.85 in.

2.2 Thickness Conversion Table (Fraction, inch, millimeter, Steel Weight lb/sqft and kg/m^2)

Frac	in.	ga	mm	lb/ft	kg/m	Frac	in.	ga	mm	lb/ft	kg/m	Frac	in.	ga	mm	lb/ft	kg/m
	0.0010		0.025	0.042	0.204		0.0179	26	0.455	0.749	3.655		0.1457		3.700	6.092	29.743
	0.0020		0.051	0.084	0.408		0.0180		0.457	0.753	3.675		0.1470		3.734	6.148	30.015
	0.0024		0.060	0.099	0.482		0.0190		0.483	0.795	3.879		0.1495	9	3.797	6.252	30.525
	0.0028		0.070	0.115	0.563		0.0197		0.500	0.823	4.019		0.1496		3.800	6.257	30.547
	0.0030		0.076	0.125	0.613		0.0200		0.508	0.836	4.084		0.1500		3.810	6.273	30.627
	0.0031		0.080	0.132	0.643		0.0209	25	0.531	0.874	4.267		0.1520		3.861	6.357	31.036
	0.0035		0.090	0.148	0.723		0.0210		0.533	0.878	4.288		0.1535		3.900	6.421	31.351
	0.0039		0.100	0.165	0.804		0.0220		0.559	0.920	4.492	5/32	0.1562		3.967	6.532	31.893
	0.0040		0.102	0.167	0.817		0.0230		0.584	0.962	4.696		0.1575		4.000	6.586	32.155
	0.0050		0.127	0.209	1.021		0.0236		0.600	0.988	4.823		0.1600		4.064	6.691	32.669
	0.0060	38	0.152	0.251	1.225		0.0239	24	0.607	0.999	4.880		0.1614		4.100	6.750	32.959
	0.0064	37	0.163	0.268	1.307		0.0240		0.610	1.004	4.900		0.1644	8	4.176	6.875	33.568
	0.0067	36	0.170	0.280	1.368		0.0250		0.635	1.046	5.105		0.1654		4.200	6.915	33.763
	0.0070		0.178	0.293	1.429		0.0260		0.660	1.087	5.309		0.1693		4.300	7.080	34.566
	0.0075	35	0.191	0.314	1.531		0.0269	23	0.683	1.125	5.493		0.1700		4.318	7.109	34.711
	0.0079		0.200	0.329	1.608		0.0270		0.686	1.129	5.513	11/64	0.1719		4.366	7.189	35.099
	0.0080		0.203	0.335	1.633		0.0276		0.700	1.153	5.627		0.1732		4.400	7.244	35.370
	0.0082	34	0.208	0.343	1.674		0.0280		0.711	1.171	5.717		0.1772		4.500	7.409	36.174
	0.0090	33	0.229	0.376	1.838		0.0290		0.737	1.213	5.921		0.1793	7	4.554	7.498	36.610
	0.0097	32	0.246	0.406	1.981		0.0299	22	0.759	1.250	6.105		0.1800		4.572	7.528	36.753
	0.0100		0.254	0.418	2.042		0.0300		0.762	1.255	6.125		0.1811		4.600	7.574	36.978
	0.0105	31	0.267	0.439	2.144		0.0310		0.787	1.296	6.330		0.1850		4.700	7.738	37.782
	0.0110		0.279	0.460	2.246	1/32	0.0312		0.792	1.305	6.371	3/16	0.1875		4.763	7.841	38.284
	0.0118		0.300	0.494	2.412		0.0315		0.800	1.317	6.431		0.1890		4.800	7.903	38.586
	0.0120	30	0.305	0.502	2.450		0.0320		0.813	1.338	6.534		0.1900		4.826	7.946	38.795
	0.0130		0.330	0.544	2.654		0.0329	21	0.836	1.376	6.718		0.1929		4.900	8.068	39.390
	0.0135	29	0.343	0.565	2.756		0.0330		0.838	1.380	6.738		0.1943	6	4.935	8.126	39.673
	0.0140		0.356	0.585	2.859		0.0340		0.864	1.422	6.942		0.1969		5.000	8.232	40.193
	0.0149	28	0.378	0.623	3.042		0.0350		0.889	1.464	7.146		0.2000		5.080	8.364	40.837
	0.0150		0.381	0.627	3.063		0.1345	10	3.416	5.625	27.463		0.2008		5.100	8.397	40.997
1/64	0.0156		0.396	0.652	3.185		0.1378		3.500	5.763	28.135	13/64	0.2031		5.159	8.494	41.470
	0.0157		0.400	0.659	3.215		0.1400		3.556	5.855	28.586		0.2047		5.200	8.562	41.801
	0.0160		0.406	0.669	3.267	9/64	0.1406		3.571	5.880	28.708		0.2087		5.300	8.726	42.605
	0.0164	27	0.417	0.686	3.349		0.1417		3.600	5.927	28.939		0.2092	5	5.314	8.749	42.715
	0.0170		0.432	0.711	3.471		0.1450		3.683	6.064	29.607		0.2100		5.334	8.782	42.878

	0.2126		5.400	8.891	43.409		0.0490		1.245	2.049	10.005		0.0750		1.905	3.136	15.312
	0.2165		5.500	9.056	44.213		0.0500		1.270	2.091	10.209		0.0760		1.930	3.178	15.516
7/32	0.2188		5.558	9.150	44.675		0.0510		1.295	2.133	10.413		0.0770		1.956	3.220	15.720
	0.2200		5.588	9.200	44.920		0.0512		1.300	2.140	10.450		0.0780		1.981	3.262	15.925
	0.2205		5.600	9.220	45.017		0.0520		1.321	2.175	10.618	5/64	0.0781		1.984	3.266	15.947
	0.2242	4	5.695	9.376	45.778		0.0530		1.346	2.216	10.822		0.0787		2.000	3.293	16.077
	0.2244		5.700	9.385	45.821		0.0538	17	1.367	2.250	10.985		0.2480		6.300	10.373	50.644
	0.2283		5.800	9.549	46.624		0.0540		1.372	2.258	11.026	1/4	0.2500		6.350	10.455	51.046
	0.2300		5.842	9.619	46.962		0.0550		1.397	2.300	11.230		0.2520		6.400	10.537	51.448
	0.2323		5.900	9.714	47.428		0.0551		1.400	2.305	11.254		0.2559		6.500	10.702	52.252
15/64	0.2344		5.954	9.803	47.860		0.0560		1.422	2.342	11.434		0.2598		6.600	10.867	53.055
	0.2362		6.000	9.879	48.232		0.0570		1.448	2.384	11.638		0.2600		6.604	10.873	53.088
	0.2391	3	6.073	9.999	48.820		0.0580		1.473	2.426	11.843		0.2638		6.700	11.031	53.859
	0.2400		6.096	10.037	49.004		0.0590		1.499	2.467	12.047	17/64	0.2656		6.746	11.107	54.231
	0.2402		6.100	10.043	49.036		0.0591		1.500	2.470	12.058		0.2677		6.800	11.196	54.663
	0.2441		6.200	10.208	49.840		0.0598	16	1.519	2.501	12.210		0.2700		6.858	11.291	55.129
	0.0354		0.900	1.482	7.235		0.0600		1.524	2.509	12.251		0.2717		6.900	11.361	55.467
	0.0359	20	0.912	1.501	7.330		0.0610		1.549	2.551	12.455		0.2756		7.000	11.525	56.271
	0.0360		0.914	1.506	7.351		0.0620		1.575	2.593	12.659		0.2795		7.100	11.690	57.075
	0.0370		0.940	1.547	7.555	1/16	0.0625		1.588	2.614	12.761		0.2800		7.112	11.710	57.171
	0.0380		0.965	1.589	7.759		0.0630		1.600	2.634	12.862	9/32	0.2812		7.142	11.760	57.416
	0.0390		0.991	1.631	7.963		0.0640		1.625	2.676	13.066		0.2835		7.200	11.854	57.879
	0.0394		1.000	1.646	8.039		0.0650		1.651	2.718	13.270		0.2874		7.300	12.019	58.683
	0.0400		1.016	1.673	8.167		0.0660		1.676	2.760	13.474		0.2900		7.366	12.128	59.213
	0.0410		1.041	1.715	8.372		0.0669		1.700	2.799	13.666		0.2913		7.400	12.184	59.486
	0.0418	19	1.062	1.748	8.535		0.0670		1.702	2.802	13.679		0.2945		7.480	12.315	60.129
	0.0420		1.067	1.756	8.576		0.0673	15	1.709	2.814	13.742		0.2953		7.500	12.348	60.290
	0.0430		1.092	1.798	8.780		0.0680		1.727	2.843	13.883	19/64	0.2969		7.541	12.416	60.622
	0.0433		1.100	1.811	8.843		0.0690		1.752	2.885	14.087		0.2992		7.600	12.513	61.094
	0.0440		1.118	1.840	8.984		0.0700		1.778	2.927	14.291		0.3000		7.620	12.546	61.255
	0.0450		1.143	1.882	9.188		0.0709		1.800	2.964	14.470		0.3031		7.700	12.678	61.898
	0.0460		1.168	1.924	9.392		0.0710		1.803	2.969	14.495		0.3071		7.800	12.842	62.702
3/64	0.0469		1.191	1.961	9.576		0.0720		1.829	3.011	14.700		0.3100		7.874	12.964	63.297
	0.0470		1.194	1.966	9.597		0.0730		1.854	3.053	14.904		0.3110		7.900	13.007	63.506
	0.0472		1.200	1.976	9.646		0.0740		1.879	3.094	15.108	5/16	0.3125		7.938	13.069	63.807
	0.0478	18	1.214	1.999	9.760		0.0747	14	1.897	3.124	15.252		0.3150		8.000	13.172	64.310
	0.0480		1.219	2.007	9.801		0.0748		1.900	3.128	15.274		0.3189		8.100	13.336	65.113

(*Continued*)

2.2 Continued

Frac	in.	ga	mm	lb/ft	kg/m	Frac	in.	ga	mm	lb/ft	kg/m	Frac	in.	ga	mm	lb/ft	kg/m
	0.3200		8.128	13.382	65.339		0.0870		2.209	3.638	17.761		0.1140		2.896	4.767	23.277
	0.3228		8.200	13.501	65.917		0.0880		2.235	3.680	17.965		0.1150		2.921	4.809	23.481
	0.3268		8.300	13.666	66.721		0.0890		2.260	3.721	18.169		0.1142		2.900	4.775	23.312
21/64	0.3281		8.334	13.721	66.992		0.0897	13	2.278	3.751	18.315		0.1160		2.946	4.851	23.685
	0.3300		8.382	13.801	67.380		0.0900		2.286	3.763	18.373		0.1170		2.972	4.893	23.889
	0.3307		8.400	13.830	67.525		0.0906		2.300	3.787	18.489		0.1180		2.997	4.935	24.094
	0.3346		8.500	13.995	68.329		0.0910		2.311	3.805	18.577		0.1190		3.023	4.977	24.298
	0.3386		8.600	14.160	69.133		0.0920		2.336	3.847	18.782		0.1181		3.000	4.939	24.116
	0.3400		8.636	14.219	69.422		0.0930		2.362	3.889	18.986		0.1196	11	3.038	5.002	24.420
	0.3425		8.700	14.324	69.937	3/32	0.0938		2.383	3.923	19.152		0.1200		3.048	5.018	24.502
11/32	0.3438		8.733	14.378	70.198		0.0940		2.387	3.930	19.190		0.1220		3.100	5.104	24.920
	0.3465		8.800	14.489	70.741		0.0945		2.400	3.951	19.293	1/8	0.1250		3.175	5.228	25.523
	0.3500		8.890	14.637	71.464		0.0950		2.413	3.973	19.397		0.1260		3.200	5.269	25.724
	0.3504		8.900	14.653	71.544		0.0960		2.438	4.015	19.602		0.1280		3.251	5.353	26.135
	0.3543		9.000	14.818	72.348		0.0970		2.464	4.057	19.806		0.1299		3.300	5.433	26.528
	0.3583		9.100	14.983	73.152		0.0984		2.500	4.116	20.097		0.1300		3.302	5.437	26.544
23/64	0.3594		9.129	15.030	73.383		0.0990		2.515	4.140	20.214		0.1320		3.353	5.520	26.952
	0.3600		9.144	15.055	73.506		0.1000		2.540	4.182	20.418		0.1339		3.400	5.598	27.332
	0.3622		9.200	15.147	73.956		0.1010		2.565	4.224	20.622		0.3819		9.700	15.971	77.975
	0.3661		9.300	15.312	74.760		0.1020		2.591	4.266	20.827		0.3858		9.800	16.135	78.779
	0.3700		9.398	15.473	75.548		0.1024		2.600	4.281	20.901		0.3898		9.900	16.300	79.583
	0.3701		9.400	15.477	75.564		0.1030		2.616	4.307	21.031		0.3900		9.906	16.310	79.631
	0.3740		9.500	15.641	76.368		0.1040		2.642	4.349	21.235	25/64	0.3906		9.921	16.335	79.754
3/8	0.3750		9.525	15.683	76.569		0.1046	12	2.657	4.374	21.358		0.3937		10.000	16.465	80.387
	0.3780		9.600	15.806	77.172		0.1050		2.667	4.391	21.439		0.3976		10.100	16.629	81.191
	0.3800		9.652	15.892	77.590		0.1060		2.692	4.433	21.643		0.4000		10.160	16.728	81.673
	0.0790		2.006	3.303	16.129		0.1063		2.700	4.445	21.704		0.4016		10.200	16.794	81.995
	0.0800		2.032	3.345	16.333		0.1070		2.718	4.475	21.848		0.4055		10.300	16.959	82.799
	0.0810		2.057	3.387	16.537		0.1080		2.743	4.517	22.052	13/32	0.4062		10.317	16.987	82.939
	0.0820		2.083	3.429	16.741		0.1090		2.769	4.558	22.256		0.4094		10.400	17.123	83.602
	0.0827		2.100	3.458	16.881	7/64	0.1094		2.779	4.575	22.338		0.4100		10.414	17.146	83.715
	0.0830		2.108	3.471	16.946		0.1100		2.794	4.600	22.460		0.4134		10.500	17.288	84.406
	0.0840		2.133	3.513	17.150		0.1110		2.819	4.642	22.664		0.4173		10.600	17.452	85.210
	0.0850		2.159	3.554	17.354		0.1102		2.800	4.610	22.508		0.4200		10.668	17.564	85.757
	0.0860		2.184	3.596	17.557		0.1120		2.845	4.684	22.868		0.4213		10.700	17.617	86.014
	0.0866		2.200	3.622	17.685		0.1130		2.870	4.726	23.073	27/64	0.4219		10.716	17.644	86.145

	0.4252	10.800	17.782	86.818		0.4567	11.600	19.099	93.249		0.4882	12.400	20.416	99.680
	0.4291	10.900	17.946	87.622		0.4600	11.684	19.237	93.924		0.4900	12.446	20.492	100.050
	0.4300	10.922	17.983	87.799		0.4606	11.700	19.264	94.053		0.4921	12.500	20.581	100.484
	0.4331	11.000	18.111	88.426		0.4646	11.800	19.428	94.857		0.4961	12.600	20.745	101.288
	0.4370	11.100	18.276	89.230		0.4685	11.900	19.593	95.661	1/2	0.5	12.700	20.910	102.091
7/16	0.4375	11.113	18.296	89.330	15/32	0.4688	11.908	19.605	95.721	9/16	0.563	14.288	23.524	114.853
	0.4400	11.176	18.401	89.841		0.4700	11.938	19.655	95.966	5/8	0.625	15.875	26.138	127.614
	0.4409	11.200	18.440	90.033		0.4724	12.000	19.757	96.464	11/16	0.688	17.463	28.751	140.376
	0.4449	11.300	18.605	90.837		0.4764	12.100	19.922	97.268	3/4	0.75	19.050	31.365	153.137
	0.4488	11.400	18.770	91.641		0.4800	12.192	20.074	98.008	13/16	0.813	20.638	33.979	165.899
	0.4500	11.430	18.819	91.882		0.4803	12.200	20.087	98.072	7/8	0.875	22.225	36.593	178.660
	0.4528	11.500	18.934	92.445		0.4843	12.300	20.251	98.876	15/16	0.938	23.813	39.206	191.422
29/64	0.4531	11.509	18.949	92.515	31/64	0.4844	12.304	20.258	98.906		1	25.400	41.820	204.183

2.3 Pressure or Stress Conversion Table psi to MPa (1000 psi = 6.894757 MPa)

1000 lb/in.^{2}	0	1	2	3	4	5	6	7	8	9
0	0.0	6.9	13.8	20.7	27.6	34.5	41.4	48.3	55.2	62.1
10	68.9	75.8	82.7	89.6	96.5	103.4	110.3	117.2	124.1	131.0
20	137.9	144.8	151.7	158.6	165.5	172.4	179.3	186.2	193.1	199.9
30	206.8	213.7	220.6	227.5	234.4	241.3	248.2	255.1	262.0	268.9
40	275.8	282.7	289.6	296.5	303.4	310.3	317.2	324.1	330.9	337.8
50	344.7	351.6	358.5	365.4	372.3	379.2	386.1	393.0	399.9	406.8
60	413.7	420.6	427.5	434.4	441.3	448.2	455.1	461.9	468.8	475.7
70	482.6	489.5	496.4	503.3	510.2	517.1	524.0	530.9	537.8	544.7
80	551.6	558.5	565.4	572.3	579.2	586.1	592.9	599.8	606.7	613.6
90	620.5	627.4	634.3	641.2	648.1	655.0	661.9	668.8	675.7	682.6
100	689.5	696.4	703.3	710.2	717.1	723.9	730.8	737.7	744.6	751.5
110	758.4	765.3	772.2	779.1	786.0	792.9	799.8	806.7	813.6	820.5
120	827.4	834.3	841.2	848.1	854.9	861.8	868.7	875.6	882.5	889.4
130	896.3	903.2	910.1	917.0	923.9	930.8	937.7	944.6	951.5	958.4
140	965.3	972.2	979.1	986.0	992.8	999.7	1006.6	1013.5	1020.4	1027.3
150	1034.2	1041.1	1048.0	1054.9	1061.8	1068.7	1075.6	1082.5	1089.4	1096.3
160	1103.2	1110.1	1117.0	1123.8	1130.7	1137.6	1144.5	1151.4	1158.3	1165.2
170	1172.1	1179.0	1185.9	1192.8	1199.7	1206.6	1213.5	1220.4	1227.3	1234.2
180	1241.1	1248.0	1254.8	1261.7	1268.6	1275.5	1282.4	1289.3	1296.2	1303.1
190	1310.0	1316.9	1323.8	1330.7	1337.6	1344.5	1351.4	1358.3	1365.2	1372.1
200	1379.0	1385.8	1392.7	1399.6	1406.5	1413.4	1420.3	1427.2	1434.1	1441.0
210	1447.9	1454.8	1461.7	1468.6	1475.5	1482.4	1489.3	1496.2	1503.1	1510.0
220	1516.8	1523.7	1530.6	1537.5	1544.4	1551.3	1558.2	1565.1	1572.0	1578.9
230	1585.8	1592.7	1599.6	1606.5	1613.4	1620.3	1627.2	1634.1	1641.0	1647.8
240	1654.7	1661.6	1668.5	1675.4	1682.3	1689.2	1696.1	1703.0	1709.9	1716.8
250	1723.7	1730.6	1737.5	1744.4	1751.3	1758.2	1765.1	1772.0	1778.8	1785.7

Example: 62 ksi (62,000 psi) = 427.5 MPa.

2.4 Pressure or Stress Conversion Table MPa to ksi (1 MPa = 0.1450377 ksi)

MPa	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
0	0.0	0.7	1.5	2.2	2.9	3.6	4.4	5.1	5.8	6.5	7.3	8.0	8.7	9.4	10.2	10.9	11.6	12.3	13.1	13.8
100	14.5	15.2	16.0	16.7	17.4	18.1	18.9	19.6	20.3	21.0	21.8	22.5	23.2	23.9	24.7	25.4	26.1	26.8	27.6	28.3
200	29.0	29.7	30.5	31.2	31.9	32.6	33.4	34.1	34.8	35.5	36.3	37.0	37.7	38.4	39.2	39.9	40.6	41.3	42.1	42.8
300	43.5	44.2	45.0	45.7	46.4	47.1	47.9	48.6	49.3	50.0	50.8	51.5	52.2	52.9	53.7	54.4	55.1	55.8	56.6	57.3
400	58.0	58.7	59.5	60.2	60.9	61.6	62.4	63.1	63.8	64.5	65.3	66.0	66.7	67.4	68.2	68.9	69.6	70.3	71.1	71.8
500	72.5	73.2	74.0	74.7	75.4	76.1	76.9	77.6	78.3	79.0	79.8	80.5	81.2	81.9	82.7	83.4	84.1	84.8	85.6	86.3
600	87.0	87.7	88.5	89.2	89.9	90.6	91.4	92.1	92.8	93.5	94.3	95.0	95.7	96.5	97.2	97.9	98.6	99.4	100.1	100.8
700	101.5	102.3	103.0	103.7	104.4	105.2	105.9	106.6	107.3	108.1	108.8	109.5	110.2	111.0	111.7	112.4	113.1	113.9	114.6	115.3
800	116.0	116.8	117.5	118.2	118.9	119.7	120.4	121.1	121.8	122.6	123.3	124.0	124.7	125.5	126.2	126.9	127.6	128.4	129.1	129.8
900	130.5	131.3	132.0	132.7	133.4	134.2	134.9	135.6	136.3	137.1	137.8	138.5	139.2	140.0	140.7	141.4	142.1	142.9	143.6	144.3
1000	145.0	145.8	146.5	147.2	147.9	148.7	149.4	150.1	150.8	151.6	152.3	153.0	153.7	154.5	155.2	155.9	156.6	157.4	158.1	158.8
1100	159.5	160.3	161.0	161.7	162.4	163.2	163.9	164.6	165.3	166.1	166.8	167.5	168.2	169.0	169.7	170.4	171.1	171.9	172.6	173.3
1200	174.0	174.8	175.5	176.2	176.9	177.7	178.4	179.1	179.8	180.6	181.3	182.0	182.7	183.5	184.2	184.9	185.6	186.4	187.1	187.8
1300	188.5	189.3	190.0	190.7	191.4	192.2	192.9	193.6	194.4	195.1	195.8	196.5	197.3	198.0	198.7	199.4	200.2	200.9	201.6	202.3
1400	203.1	203.8	204.5	205.2	206.0	206.7	207.4	208.1	208.9	209.6	210.3	211.0	211.8	212.5	213.2	213.9	214.7	215.4	216.1	216.8
1500	217.6	218.3	219.0	219.7	220.5	221.2	221.9	222.6	223.4	224.1	224.8	225.5	226.3	227.0	227.7	228.4	229.2	229.9	230.6	231.3
1600	232.1	232.8	233.5	234.2	235.0	235.7	236.4	237.1	237.9	238.6	239.3	240.0	240.8	241.5	242.2	242.9	243.7	244.4	245.1	245.8
1700	246.6	247.3	248.0	248.7	249.5	250.2	250.9	251.6	252.4	253.1	253.8	254.5	255.3	256.0	256.7	257.4	258.2	258.9	259.6	260.3
1800	261.1	261.8	262.5	263.2	264.0	264.7	265.4	266.1	266.9	267.6	268.3	269.0	269.8	270.5	271.2	271.9	272.7	273.4	274.1	274.8
1900	275.6	276.3	277.0	277.7	278.5	279.2	279.9	280.6	281.4	282.1	282.8	283.5	284.3	285.0	285.7	286.4	287.2	287.9	288.6	289.4
2000	290.1	290.8	291.5	292.3	293.0	293.7	294.4	295.2	295.9	296.6	297.3	298.1	298.8	299.5	300.2	301.0	301.7	302.4	303.1	303.9

Example: 345 MPa = 50 ksi (50,000 psi).

2.5 Temperature Conversion Table

C	*X*	F															
−128.9	−200	−328.0	−21.1	−6	21.2	−7.8	18	64.4	3.9	39	102.2	15.6	60	140.0	27.2	81	177.8
−115.0	−175	−283.0	−20.0	−4	24.8	−7.2	19	66.2	4.4	40	104.0	16.1	61	141.8	27.8	82	179.6
−101.1	−150	−238.0	−18.9	−2	28.4	−6.7	20	68.0	5.0	41	105.8	16.7	62	143.6	28.3	83	181.4
−87.2	−125	−193.0	−17.8	0	32.0	−6.1	21	69.8	5.6	42	107.6	17.2	63	145.4	28.9	84	183.2
−73.3	−100	−148.0	−17.2	1	33.8	−5.6	22	71.6	6.1	43	109.4	17.8	64	147.2	29.4	85	185.0
−59.4	−75	−103.0	−16.7	2	35.6	−5.0	23	73.4	6.7	44	111.2	18.3	65	149.0	30.0	86	186.8
−45.6	−50	−58.0	−16.1	3	37.4	−4.4	24	75.2	7.2	45	113.0	18.9	66	150.8	30.6	87	188.6
−40.0	−40	−40.0	−15.6	4	39.2	−3.9	25	77.0	7.8	46	114.8	19.4	67	152.6	31.1	88	190.4
−37.2	−35	−31.0	−15.0	5	41.0	−3.3	26	78.8	8.3	47	116.6	20.0	68	154.4	31.7	89	192.2
−34.4	−30	−22.0	−14.4	6	42.8	−2.8	27	80.6	8.9	48	118.4	20.6	69	156.2	32.2	90	194.0
−33.3	−28	−18.4	−13.9	7	44.6	−2.2	28	82.4	9.4	49	120.2	21.1	70	158.0	32.8	91	195.8
−32.2	−26	−14.8	−13.3	8	46.4	−1.7	29	84.2	10.0	50	122.0	21.7	71	159.8	33.3	92	197.6
−31.1	−24	−11.2	−12.8	9	48.2	−1.1	30	86.0	10.6	51	123.8	22.2	72	161.6	33.9	93	199.4
−30.0	−22	−7.6	−12.2	10	50.0	−0.6	31	87.8	11.1	52	125.6	22.8	73	163.4	34.4	94	201.2
−28.9	−20	−4.0	−11.7	11	51.8	0.0	32	89.6	11.7	53	127.4	23.3	74	165	35.0	95	203.0
−27.8	−18	−0.4	−11.1	12	53.6	0.6	33	91.4	12.2	54	129.2	23.9	75	167.0	35.6	96	204.8
−26.7	−16	3.2	−10.6	13	55.4	1.1	34	93.2	12.8	55	131.0	24.4	76	168.8	36.1	97	206.6
−25.6	−14	6.8	−10.0	14	57.2	1.7	35	95.0	13.3	56	132.8	25.0	77	170.6	36.7	98	208.4
−24.4	−12	10.4	−9.4	15	59.0	2.2	36	96.8	13.9	57	134.6	25.6	78	172.4	37.2	99	210.2
−23.3	−10	14.0	−8.9	16	60.8	2.8	37	98.6	14.4	58	136.4	26.1	79	174.2	37.8	100	212.0
−22.2	−8	17.6	−8.3	17	62.6	3.3	38	100.4	15.0	59	138.2	26.7	80	176.0	38.3	101	213.8

38.9	102	215.6	52.2	126	258.8	87.8	190	374.0	187.8	370	698	329.4	625	1157	760.0	1400	2552
39.4	103	217.4	52.8	127	260.6	90.6	195	383.0	193.3	380	716	343.3	650	1202	787.8	1450	2642
40.0	104	219.2	53.3	128	262.4	93.3	200	392.0	198.9	390	734	357.2	675	1247	815.6	1500	2732
40.6	105	221.0	53.9	129	264.2	96.1	205	401.0	204.4	400	752	365.6	690	1274	871.1	1600	2912
41.1	106	222.8	54.4	130	266.0	98.9	210	410	210.0	410	770	371.1	700	1292	926.7	1700	3092
41.7	107	224.6	55.0	131	267.8	101.7	215	419	215.6	420	788	385.0	725	1337	982.2	1800	3272
42.2	108	226.4	55.6	132	269.6	104.4	220	428	221.1	430	806	398.9	750	1382	1037.8	1900	3452
42.8	109	228.2	56.1	133	271.4	107.2	225	437	226.7	440	824	412.8	775	1427	1093.3	2000	3632
43.3	110	230.0	56.7	134	273.2	110.0	230	446	232.2	450	842	426.7	800	1472	1148.9	2100	3812
43.9	111	231.8	57.2	135	275.0	112.8	235	455	237.8	460	860	440.6	825	1517	1204.4	2200	3992
44.4	112	233.6	57.8	136	276.8	115.6	240	464	243.3	470	878	454.4	850	1562	1260.0	2300	4172
45.0	113	235.4	58.3	137	278.6	118.3	245	473	248.9	480	896	468.3	875	1607	1315.6	2400	4352
45.6	114	237.2	58.9	138	280.4	121.1	250	482	254.4	490	914	482.2	900	1652	1343.3	2450	4442
46.1	115	239.0	59.4	139	282.2	126.7	260	500	260.0	500	932	496.1	925	1697	1371.1	2500	4532
46.7	116	240.8	60.0	140	284.0	132.2	270	518	265.6	510	950	510.0	950	1742	1426.7	2600	4712
47.2	117	242.6	62.8	145	293.0	137.8	280	536	271.1	520	968	523.9	975	1787	1482.2	2700	4892
47.8	118	244.4	65.6	150	302.0	143.3	290	554	276.7	530	986	537.8	1000	1832	1537.8	2800	5072
48.3	119	246.2	68.3	155	311.0	148.9	300	572	282.2	540	1004	565.6	1050	1922	1593.3	2900	5252
48.9	120	248.0	71.1	160	320.0	154.4	310	590	287.8	550	1022	593.3	1100	2012	1648.9	3000	5432
49.4	121	249.8	73.9	165	329.0	160.0	320	608	293.3	560	1040	621.1	1150	2102			
50.0	122	251.6	76.7	170	338.0	165.6	330	626	298.9	570	1058	648.9	1200	2192			
50.6	123	253.4	79.4	175	347.0	171.1	340	644	304.4	580	1076	676.7	1250	2282			
51.1	124	255	82.2	180	356.0	176.7	350	662	310.0	590	1094	704.4	1300	2372			
51.7	125	257.0	85.0	185	365.0	182.2	360	680	315.6	600	1112	732.2	1350	2462			

Conversion: C = Celsius Degree; C degree = (9/5 × F degree) + 32; F degree = (C degree − 32) × 5/9; X = C or F degrees converted from; F = Fahrenheit degree.

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